ELECTRICAL

ENGINEERING LEAFLETS

BY

dwin ames

PROFESSOR E. J. HOUSTON, PH. D.

AND

PROFESSOR A. E. KENNELLY, F.R.A.S.

ELEMENTARY GRADE

1895

THE ELECTRICAL ENGINEER

NEW YORK

PREFACE.

THE Electrical Engineering Leaflets have been prepared for the purpose of presenting, concisely but accurately, some of the fundamental principles of electrical science, as employed in engineering practice. They have been arranged under three grades; namely, the Elementary, the Intermediate, and the Advanced.

The Elementary Grade is intended for those electrical artisans, linemen, motormen, central station workmen, or electrical mechanics generally, who may not have advanced sufficiently far in their studies to warrant their undertaking the other grades. Here the mathematical treatment is limited to arithmetic, and the principles are illustrated by examples taken from actual practice.

The Intermediate Grade is intended for students of electricity in high schools and colleges. In this grade a certain knowledge of the subjects of electricity and physics generally is assumed, and a fuller mathematical treatment is adopted. These leaflets, moreover, contain such information concerning the science of electricity, as should be acquired by those desiring general mental culture.

The Advanced Grade is designed for students taking special courses in electrical engineering in colleges or universities. Here the treatment is more condensed and mathematical than in the other grades.

Although the three grades have been especially pre-

pared for the particular classes of students referred to, yet it is believed that they will all prove of value to the general reading public, as offering a ready means for acquiring that knowledge, which the present extended use and rapidly increasing commercial employment of electricity necessitates.

Laboratory of Houston & Kennelly,
Philadelphia, March, 1895.

CONTENTS.

ELEMENTARY GRADE.

		PAGE.
No. 1.	Electrical Effects	1
" 2.	Electromotive Force	9
" 3.	Electric Resistance	17
" 4.	Electric Resistance	25
" 5.	Electric Resistance	33
" 6.	Electric Current	41
" 7.	Ohm's Law	49
" 8.	Electric Circuits	57
" 9.	The Voltaic Cell	65
" 10.	The Voltaic Cell	73
" 11.	The Voltaic Cell	81
" 12.	Magnetomotive Force	89
" 13.	Magnetic Reluctance	97
" 14.	Magnetic Flux	105
" 15.	Electromagnets	113
" 16.	Induced E. M. F	121
" 17.	The Dynamo	129
" 18.	The Dynamo	137
" 19.	The Dynamo	145
" 20.	The Regulation of the Dynamo	153

		PAGE.
No. 21.	Electrodynamics	161
" 22.	The Electric Motor, (Continuous Current Type)	169
" 23.	The Electric Motor, (Continuous Current Type)	177
" 24.	The Electric Motor, (Continuous Current Type)	184
" 25.	Electric Heating	193
" 26.	Incandescent Lighting	201
" 27.	Incandescent Lighting	209
" 28.	Arc Lighting	217
" 29.	Arc Lighting	225
" 30.	Alternating Currents	233
" 31.	Alternating Currents	241
" 32.	Alternating Currents	249
" 33.	Alternators	257
" 34.	Alternators	265
" 35.	Alternating Current Transformers	273

WEEKLY.

No. 1. JUNE 16, 1894. Price, - 10 Cents. Subscription, $3.00.

Electrical Engineering Leaflets,

—BY—

Prof. E. J. Houston, Ph. D.

AND

A. E. Kennelly, F. R. A. S.

ELEMENTARY GRADE.

ELECTRICAL EFFECTS.

---

1. If on a dry day, a hard rubber comb be briskly rubbed on a dry coatsleeve, the comb will be found to attract light pieces of paper. Under favorable conditions a crackling sound will also be heard, and if the experiment be tried in the dark, bluish flashes of feeble light will be seen round the comb. If, after vigorous rubbing the comb be drawn near the face, a peculiar sensation will be experienced like that of the passage of cobwebs over it. These are some of the effects produced by electricity.

The same effects are intensified if the comb be rubbed upon a piece of catskin or fur, instead of upon the coat.

2. A leather belt moving rapidly over a pulley, will, under certain conditions, produce powerful electrical effects, and if a knuckle of the hand be held near the belt, sparks will appear between the knuckle and belt, accompanied by a sharp crack and a more or less severe shock to the experimenter.

Published by
THE ELECTRICAL ENGINEER,
203 Broadway, New York, N. Y.

[Entered as second-class matter at the New York, N. Y., Post Office, June 14, 1894.]

3. When a lightning flash passes between two neighboring clouds, or between a cloud and some object on the earth, a sharp report—thunder—accompanies the flash, and occasionally a peculiar smell is presently observed. When the conducting path offered for the lightning discharge is insufficient, destructive effects occur, such as the rending or tearing of timber, the splitting of masonry, or the melting of metal work.

4. When the comb is rubbed over the coat we obtain what is called an *electric charge*, and we charge both the comb and the coat. When a spark passes between comb and coat, from belt to knuckle, or from cloud to earth, we see some of the evidences of an *electric discharge*.

An electric discharge produces a momentary *electric current*. If electric discharges follow one another with sufficient rapidity they lose their momentary character, and may develop into a steady electric stream or current.

5. *Dynamo electric machines*, as is well known, produce powerful electric currents. These currents heat the armature of the dynamo to a degree readily perceptible to the touch; are able to raise the temperature of the filament of an incandescent lamp so that it shines; may fuse a conducting wire when that wire is too small, and can produce a luminous discharge, called the "*arc*," between carbon rods in an arc lamp. If accidentally passed through the human body, such currents may produce severe injury or even death.

Besides the above electric effects, there are others not yet mentioned. If a bar of iron be approached to the magnets of a dynamo while it is producing electric cur-

rent, a strong magnetic pull will be felt on the iron. This effect is due to the magnetic action of the electric current passing through the coils of wire round the magnets. Magnetism, therefore, is one of the effects produced by electricity.

6. When an electric current is led through a bath containing an electroplating solution, metal is separated from the solution and deposited upon objects suitably connected to the leading-in wires. Chemical decomposition caused by electric currents is called *electrolysis*, which is, therefore, another electric effect.

7. Electric discharges, therefore, produce a variety of effects which may be classified as follows:

(*1*.) Luminous, as in the electric spark or light.

(*2*.) Heating, as in fusing wire or warming armature.

(*3*.) Mechanical, as in effects of lightning discharge.

(*4*.) Physiological, as in shock to human body.

(*5*.) Magnetic, as in the attraction of a bar of iron by dynamo magnets.

(*6*.) Electrolytic, as in electro-plating.

8. A cart or car never moves of itself on a level road, but must be pushed or pulled. A clock to continue to run, must either have its weight raised or its spring wound up. A locomotive steam engine cannot run on a level unless driven by steam produced by the action of heat on the water in a boiler.

To permit water to fall out of a vessel it must first be raised into the vessel. The water which flows down to the sea through a river channel has first to be lifted by the sun's heat as vapor from the ocean, and deposited as rain on the high lands where the river begins. (Fig. 1.)

An incandescent or arc lamp will not shine, nor an electric motor run, unless supplied by an electric current.

The speed with which a ball leaves a gun depends upon the amount of powder used in the gun barrel. The power of the ball to overcome obstacles, comes from the heat produced by the burning of the powder.

Muscular power in any animal is derived from the food the animal consumes, which food is slowly burned away in the animal's body.

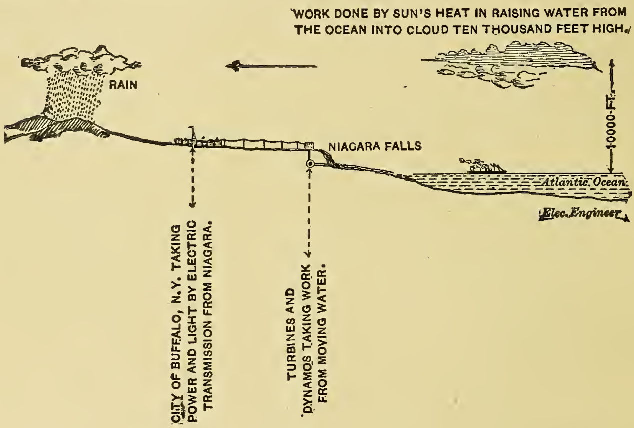


FIG. 1.

9. In all these cases *work* has been done as is shown by matter having been moved through a distance, and in order to produce the motion, some force has been brought to bear upon the body. The cart or car on the level road required to receive a push or pull; the pendulum of the clock needed the action of a weight or spring; the locomotive steam engine required to be driven by the pressure of the steam against the piston in the cylinder; the water to fall out of the vessel required

to be acted on by the earth's attraction, *i. e.*, by gravity; the water in the river, in order to flow through its channel, requires gravitational force; the ball in the gun barrel, in order to be set in motion, requires the pressure of the expanding hot gases in the barrel.

10. But in none of these cases is work done unless the force acting on the body causes the body to move. A weight resting on a table produces a pressure or force upon the table, but no work is done so long as it remains at rest; but as soon as the table is withdrawn from beneath the weight, the force of gravity moves the weight through a distance; *i. e.*, to the ground, and does work. (Fig. 2.)

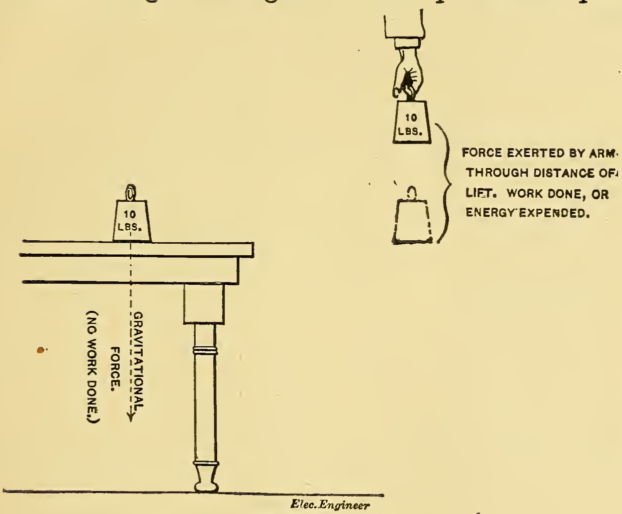


Fig. 2.

11. In no case is work done, *i. e.*, by force acting through a distance, without drawing upon a stock of previous work. The cart or car, moved along the

level road, required work to be done on it by an animal, and this store of work in the animal was obtained from its food, which in its turn received its store of work from the sun's light and heat.

The clock, in order to do work, required to be wound up, say by a man, who obtained his store of work in the same way, and there is less work in a man or animal after exerting force through a distance than there was before; the man or animal, therefore, requires to eat in order to replenish his stock of work.

The locomotive steam engine, or any steam engine, has to burn coal in order to obtain the work it exerts, and the coal in its turn, receives its stock of work from the sun.

The water in the river can only fall towards the sea by the work done on it by the sun's heat in lifting it from the sea to the clouds.

The incandescent or arc lamp can only shine and produce its heat and light; *i. e.*, work, by the work done on it by the electric current, which received its store of work from the dynamo, which received its store from the steam engine, which again received it from the coal, and this finally from the sun's rays.

Work is consequently never done without drawing upon a stock of previous work. All machines are devices for transferring work from a store or stock where it is not wanted; for example, from the work of the sun's rays in coal, to where it is wanted, namely in a steam engine.

It should carefully be borne in mind that electrical work, *i. e.*, work performed by electricity in producing any electrical effects, is no exception to this rule; such work has to be paid for by the expenditure of some other

store of work, such as work in coal with a steam engine, or in moving water with a water wheel, or chemical work in a voltaic battery.

12. In this general sense, work is never lost, but only transformed. It is believed that the total store or stock of work in the whole universe is constant. When any work disappears in one form it must reappear in another form. For this reason the work done by the machine can never exceed the work it withdraws from other sources. In point of fact, the amount of useful work done by the machine is always less than the work

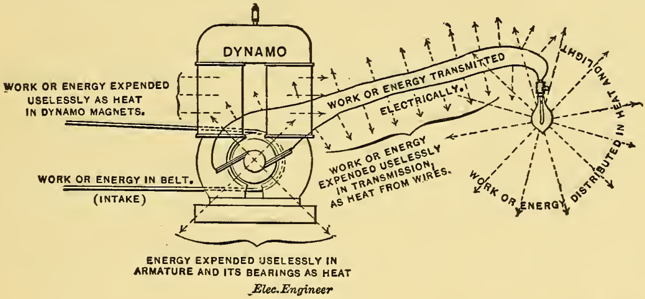


FIG. 3.

it absorbs, for the reason that in the transformation some of the work is sure to appear in a form which cannot be usefully employed. Thus the work done by a steam engine is less than the work it absorbs, partly by reason of the friction of its moving parts, which friction transforms that amount of work into heat at the rubbing surfaces, where it cannot be usefully employed. See Fig. 3.

It would be as hopeless to attempt to withdraw from a machine, electrical or otherwise, more work than it absorbs, as it would be to expect to draw, without refilling, a quart of water out of a pint vessel, and any attempt to produce

a machine, electrical or otherwise, which will continually move without absorbing work from some store or stock, is as futile as to attempt to fill the Atlantic Ocean from a simple pitcher full of water.

13. The work *done on* a machine in driving it, is termed its *intake of work*, and the *useful* or *available* work *done by* the machine is termed its *output*. *The output can never exceed the intake; in fact it can never practically even equal it.*

The amount of work performed in any case is nearly always measureable, whether it exists as heat, electricity, magnetism, chemical power, or muscular power, and can be expressed as a weight moved through a certain distance.

The amount of work required to produce any ordinary electric effect, such as lighting an incandescent lamp, depositing metal in a bath, or driving a motor, is fixed and definite, and can, in most cases, be readily measured, so that the amount of coal which must be burned in a good steam engine to produce a given electric effect can be arrived at.

Any attempt, for instance, to produce a primary battery, or any other electric device, which shall work for an indefinitely long time, without constantly requiring replenishing with a corresponding amount of work, is as futile as the attempt to produce perpetual motion without the continual absorption of energy.

Laboratory of Houston & Kennelly,
Philadelphia.

WEEKLY.

No. 2. JUNE 23, 1894. Price, - 10 Cents. Subscription, $3.00.

Electrical Engineering Leaflets,

—BY—

Prof. E. J. Houston, Ph. D.

AND

A. E. Kennelly, F. R. A. S.

ELEMENTARY GRADE.

ELECTROMOTIVE FORCE.

14. The name *electromotive force* is given to the unknown cause which produces an electric current. Since a dynamo produces an electric current it must, therefore, produce an electromotive force to set up that current. Similarly a voltaic battery produces an electromotive force, and also the rubbing of a rubber comb on the coat sleeve. In brief, anything which produces an electric current must first produce an electromotive force.

Electromotive forces are measured in *volts*. A bluestone or gravity cell, such as is used in telegraphy, has an electromotive force of about one volt. Dynamo electric machines can be built to produce an electromotive force of from one to seven thousand volts or more according to requirements.

15. Water flows naturally from a higher to a lower level, and this flow may be said to be caused by the difference of level, or "head." We speak of a head

Published by
THE ELECTRICAL ENGINEER,
203 Broadway, New York, N. Y.

[Entered as second-class matter at the New York, N. Y., Post Office, June 14, 1894.]

of water in a tank of ten, twenty or fifty feet, and the pressure from this head is what tends to drive the water forward in an outflow pipe. So the electric pressure or electromotive force of ten, twenty, or fifty volts, tends to drive electricity forward in a conducting wire, that is, to produce an electric current.

Although we have compared electricity flowing through a wire with water flowing through a pipe, yet this comparison is for illustration only, since we do not yet know what electricity really is.

16. Electromotive force, generally written for convenience E. M. F., does no work so long as it is producing no current. In this sense it is similar to the case considered in paragraph 9, where it is shown that no work is done by a pressure or force which is not acting through a distance. Thus a voltaic battery, when its terminals are disconnected, is producing its full E. M. F., but is doing no work because the E. M. F. can produce no current. Again, a dynamo on "broken" or "open circuit" *i. e.*, with its terminals not connected with the line or with each other, may be producing its full E. M. F. but requires very little work from the steam-engine to drive it, because it is not supplying current.

17. Any device or apparatus for the production of an electric current is termed generally an *electric source*. Strictly speaking, however, electric sources do not directly produce electric currents, but electromotive forces only, which electromotive forces when capable of acting, produce electric current.

There are numerous electric sources; the most important of these can be grouped under the following classes.

(*1.*) Frictional electric machines.
(*2.*) Dynamo electric machines.
(*3.*) Voltaic batteries.
(*4.*) Thermo-electric piles.

18. A frictional machine produces an electromotive force by rubbing a plate or cylinder, usually of glass, against a leather cushion. The electromotive force produced by such a machine may be very high, hundreds of thousands of volts, though for reasons that will be fully explained in a subsequent leaflet, the current actually produced is always very small. As a proof of the high electric pressure or E. M. F. generated by a frictional machine, it is sufficient to approach the knuckle near one of the insulated brass knobs of the machine, when an electric spark will dart to the hand, even though several inches away.

19. In dynamo electric machines, electromotive force is usually produced in coils of wire wrapped on a rotating part called the *armature*, by their motion through the magnetized space between the magnet poles. The E. M. F. or pressure generated by dynamo machines is usually much lower than that produced by frictional electric machines, but for reasons which will also be explained in a subsequent leaflet, dynamo electric machines are capable of producing powerful electric currents.

20. In a voltaic cell, the E. M. F. is produced by the contact of the metals of the plates with the exciting liquid. The work done by the cell when its circuit is closed, and its E. M. F. is producing a current, is supplied by the slow burning or consumption of the

zinc plate in the liquid. This is similar to the production of work in a steam engine by the burning of coal.

The E. M. F. produced by different forms of voltaic cells varies between half a volt, and two volts and a half. When, therefore, it is required to produce a higher E. M. F., with voltaic cells, it is necessary to connect a number of such cells so that they may act as a single electric source. Such a series or combination of cells is called a voltaic battery. For example, to produce a pressure of 30 volts from voltaic cells, each of which is capable of furnishing one volt, it would be necessary to connect a series of thirty such cells into a single source or battery.

21. In a thermo-pile the E. M. F. is produced by the contact of dissimilar metals when heated. In a thermo-electric couple the E. M. F. produced is very small, so that a thermo-electric battery has to be made up of a large number of thermo-electric couples connected with one another like the separate cells in a voltaic battery; *i. e., in series.*

For example, a single copper-iron thermo-couple, whose two junctions are at the boiling point and freezing point of water respectively, has a total E. M. F. of about $\frac{1}{700}$ volt.

The thermo-pile has never yet been practically employed as an electric source for the production of any considerable amount of work, and the same remark applies to frictional electric machines. The reasons in the two cases are, however, opposite. The thermo-pile can supply a moderate current with a total E. M. F. of only a few volts, while the frictional machine can supply a very powerful E. M. F. but only a very feeble, intermittent and irregular current.

22. When the E. M. F. is sufficiently high, it is liable to produce a spark discharge. For example, an electric pressure or E. M. F. of 10,000 volts will produce a "jump spark" of about $\frac{1}{8}$ inch between blunt or rounded metal surfaces, or about $\frac{3}{4}$ inch between sharp points; for, it is well known that a spark discharge passes more readily between sharp points than between blunt or rounded surfaces. In a jump spark the discharge passes without the metal surfaces being first brought into contact and afterwards separated. Were this done, a much smaller E. M. F. would be sufficient to produce a spark through the same distance.

In air, under ordinary conditions, it takes an E. M. F. of roughly 80,000 volts per inch of distance to produce a spark without prior contact. But this rule is probably only reliable up to about five inches of distance. The E. M. F. which produces a lightning flash about a mile long must, however, be very great, and is probably reckoned in millions of volts.

23. Under ordinary circumstances there is no danger to life from small E. M. F.'s, say under 200 volts. A higher E. M. F., say over 500 volts, increases the danger, owing to its capability of sending strong currents through the body when brought into accidental connection therewith.

Since, as already mentioned, an ordinary arc lamp requires 45 volts pressure to operate it, and there are frequently many (say 50) arc lamps connected in series in one circuit, the total pressure at the dynamo may be more than $50 \times 45 = 2250$ volts. Great care is, therefore, necessary in operating or handling such machines,

to avoid allowing this E. M. F. to send a current through the body, since such a current might readily be fatal.

Similarly, in climbing poles that carry arc light wires, there is a danger of coming into contact with such wires at a high pressure. And, moreover, a danger exists of carelessly handling apparently dead or idle wires on the same poles, since accidental contact may connect them with the high pressure arc light wires, and thus make them as dangerous as the arc light wires themselves.

Again, in replacing the carbons of an arc lamp the danger of a high pressure shock is not necessarily removed by closing the switch, and thus short circuiting the lamp, since contact may accidently take place through the body between the arc line and ground, and such contacts are especially dangerous on iron poles in wet weather.

In all cases where it is necessary to manipulate or adjust the brushes of a high pressure dynamo, it is advisable to keep one hand in the pocket, for a discharge through any conductor, such, for example, as the human body, must have an exit as well as an entrance, and contact with a high pressure on a single hand cannot be hurtful if the other hand is not brought near a conductor. Since, however, the ground is a conductor, it should be borne in mind that the feet may already have been brought into contact with one of the poles of the dynamo through a damp floor or the ground. It is, therefore, unsafe to touch a high pressure dynamo brush with even a single hand, unless the feet rest on dry woodwork, or other equally good non-conductor.

24. Various expedients are adopted to increase the E. M. F. of electric sources.

The E. M. F. of a frictional machine can usually be in-

creased by driving it faster; *i. e.*, by increasing the friction.

The E. M. F. of a dynamo machine may be increased by driving the armature faster; *i. e.*, by increasing the number of revolutions of the armature per minute.

The E. M. F. of a voltaic cell cannot usually be increased if the cell is in good working order. Should, however, the exciting liquid be nearly exhausted, its renewal will tend to restore the E. M. F. For the same reason, shaking or stirring a voltaic cell in use, except in the case of the "gravity" cell, will, by bringing fresh portions of the liquid in contact with the plates, restore the E. M. F. to its ordinary value. A high temperature usually lowers the E. M. F. of a cell. The E. M. F. of a thermopile can usually be increased by increasing the temperature of the heated portions of the pile.

Syllabus.

Electromotive force is the name given to the unknown cause which produces electric current.

Electromotive forces are measured in volts.

Water flows from a higher to a lower level by reason of a difference of level or head between the two levels. A head of fifty feet will produce a greater flow than a head of twenty feet.

An electric current passes through a conductor by reason of an electric pressure or electromotive force.

An E. M. F. of fifty volts will produce a greater current than an E. M. F. of twenty volts in the same circuit.

An electromotive force is doing no work unless producing an electric current. In this sense it is like a force which does no work unless it is acting through a distance.

An electric source is a device or apparatus for producing an electromotive force or electric pressure.

The electromotive force of a dynamo electric machine, as generally constituted, is produced by the motion of conductors between magnetic poles.

The electromotive force of a voltaic cell is produced by the contact of the metal in the plates with the exciting liquid.

When the E. M. F. is causing a current, the work done is due to the slow burning of the zinc plate in the liquid.

When the E. M. F. of a source is very high, a spark discharge, commonly called a jump spark, may take place between the source and an approached body without their actual contact.

Under ordinary circumstances an E. M. F. of about 80,000 volts is required for every inch up to five inches of jump spark discharge in air.

Care should be exercised in working near dynamos, or lines carrying high electromotive forces, since the discharges through the body caused by the high E. M. F.'s may be fatal.

The E. M. F. of a frictional machine or a dynamo may be increased by increasing the speed of rotation. The E. M. F. of a battery except the "gravity" cell may be increased generally by shaking the cell, if the liquid has been steadily in use for some time. The E. M. F. of a thermo-electric pile may be generally increased by increasing the temperature of the heated parts.

Laboratory of Houston & Kennelly,
Philadelphia.

WEEKLY.

No. 3. June 30, 1894. Price, - 10 Cents. Subscription, $3.00.

Electrical Engineering Leaflets,

—BY—

Prof. E. J. Houston, Ph. D.
AND
A. E. Kennelly, F. R. A. S.

ELEMENTARY GRADE.

Electric Resistance.

25. The quantity of water which will flow through a straight pipe connected with a large reservoir filled with water, depends upon the length and cross section of the pipe. The greater the length of the pipe, the greater the resistance to the passage of the water, and hence the smaller the flow or discharge. The greater the area of cross section, that is, the larger the pipe, the less the resistance to the passage of the water, and the greater the flow or discharge.

The quantity of electricity which will flow through a circuit connected with an electric source, depends upon the length and cross-section of the conductor forming the circuit. The greater the length of the conductor, the greater the resistance to the passage of the current, and hence the smaller the current strength. The greater the cross-sectional area of the conductor, that is, the larger the wire, the less the resistance to the passage of the current, and the greater the current strength.

Published by
THE ELECTRICAL ENGINEER,
203 Broadway, New York, N. Y.

[Entered as second-class matter at the New York, N. Y., Post Office, June 14, 1894.]

26. But, the length and diameter of the pipe remaining the same, the quantity of water which flows through the pipe, in a given time, will depend upon the kind of pipe and the smoothness of its walls. So in the case of a circuit, the length and area of cross-section remaining the same, the quantity of electricity which passes in a given time, that is, the strength of electric current, will depend upon the material of the conductor and the condition in which that material exists.

Just as the resistance of a water pipe is that quality which enables it to limit the flow of water through it, under fixed conditions, that is, to restrict the flow to a given amount, so the resistance of a conductor, or conducting circuit, is that quality which enables it to limit the flow of electricity through it under fixed conditions, that is, to restrict it to a given current strength.

27. The resistance of any conductor, or conducting circuit, depends, therefore, on three things; namely,

(*1.*) The length of the conductor.

(*2.*) The cross-sectional area of the conductor.

(*3.*) The kind of material of which the conductor is formed.

In order to form clear ideas, and so be able to compare the resistance of different circuits or conductors, a unit or standard of resistance has been agreed upon; namely, the resistance offered by a standard length and cross section of a definite material, at a fixed temperature.

This standard resistance is called the *International ohm.* It is accepted as being equal to the resistance offered by a column of pure mercury, $41\frac{85}{100}$ inches long, and $\frac{645}{10000}$ square inch in uniform cross section, at the temperature of melting ice.

Thus one mile of good standard copper wire, No. 7 A. W. G. (American Wire Gauge), or B. & S. (Brown & Sharpe) guage, has a resistance at ordinary temperatures of 0.0005 ohm ($\frac{1}{2000}$ ohm) per foot, or $2\frac{62}{100}$ ohms per mile.

One foot of No. 40 A. W. G. pure soft copper wire has approximately a resistance of one ohm at 50° F.

28. Since we have shown that the resistance of any wire increases directly with its length, it is evident that half a mile of No. 7 A. W. G. copper wire would

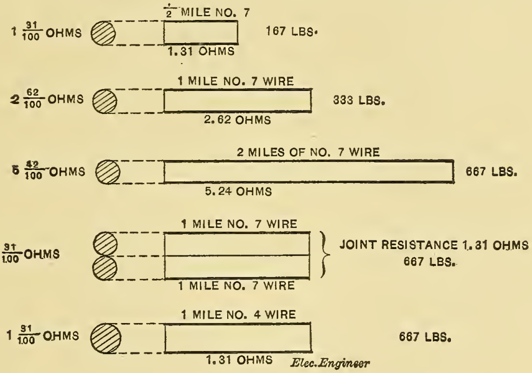


FIG. 4.

have a resistance of one-half of $2\frac{62}{100}$ ohms, namely $1\frac{31}{100}$ ohm; and the resistance of ten miles of such wire would be ten times $2\frac{62}{100}$, or $26\frac{2}{10}$ ohms. This wire would weigh 333 lbs. per mile.

No. 4 A. W. G. copper wire weighs 667 lbs. per mile, or has almost double the weight of No. 7, and must, therefore, have almost twice the cross section of No. 7. It will, therefore, have half the resistance of one mile of No. 7, or $1\frac{31}{100}$ ohms per mile. Consequently, two No. 7

A. W. G. copper wires, laid side by side, having jointly almost the same weight and cross section as one No. 4 A. W. G. wire, will have jointly about the same resistance as one No. 4 wire ($1\frac{31}{100}$ ohms per mile). See Fig. 4.

We have seen, however, that the resistance of a conductor varies with the kind of material. If, for example, the No. 7 A. W. G. wire were of iron, instead of copper, its resistance, instead of being $2\frac{62}{100}$ ohms per mile, would be about 17 ohms per mile, or $6\frac{1}{2}$ times greater; so that it is only necessary to take the resistance of any length and diameter of good copper wire and multply it by $6\frac{1}{2}$, in order to obtain the approximate resistance of the same length and diameter of good iron wire.

29. Not only, however, must the kind of material of which the wire is composed be taken into account, when calculating its resistance, but also its condition, whether it is soft or hard, that is, annealed, or hard drawn, its temperature, and degree of purity, that is, freedom from admixture with other substances.

Hard wires of any kind always have more resistance than soft wires carefully annealed. Thus, hard copper has a resistance of about $2\frac{1}{4}$ per cent. more than soft copper.

The resistance of all metals increases with the temperature. Thus, the resistance of the armature of a dynamo, after reaching a temperature of, say, 175° F., is about 24 per cent. greater than at ordinary temperatures, (68° F.) The resistance of copper increases, roughly, nearly one-quarter of one per cent. per degree Fahrenheit.

The resistance of carbon diminishes with temperature. The carbon filament of an incandescent lamp has about

half of the resistance at the incandescing temperature, that it has when cold.

Alloys, that is, combinations or mixtures of metals, always have a higher resistance than that of the best conducting metal which they contain. In fact, a very small admixture of such metal, for example, as lead in a copper wire, produces a much greater resistance than that possessed by a pure copper wire of the same dimensions. It is, therefore, very important that the copper employed for dynamos, conducting wires, or other similar electric apparatus, should be as pure as is commercially obtainable.

30. Heretofore we have regarded conductors or conducting circuits as valuable or useful in proportion to the extent to which they permit a current to pass through them, and in all these cases, an increase of resistance is a positive disadvantage. In practice, however, numerous cases exist where the obstruction to the passage of a current, that is, its resistance, is a positive advantage. Resistance, introduced for such purposes into a circuit, usually take the form of coils of wire.

Resistances of this kind are of two distinct classes, *i. e.*: (*1.*) Fixed or constant resistances, whose value estimated in ohms, remains always sensibly the same. (*2.*) Adjustable or variable resistances, in which the amount of the resistance can be controlled. Adjustable resistances, controlled by hand, are called *rheostats*. It is evident that the amount of resistance required in any particular coil could be obtained by using a great length of comparatively thick wire. As this would be an expensive, bulky, and heavy combination, a resistance coil is usually constructed of a comparatively short length of fine wire,

provision being made for the escape of the heat that may be produced by the current.

31. Artificial resistances usually take the form of coils of wire, insulated with a wrapping, or wrappings, of silk or cotton and wound on wooden bobbins. The wire is usually made from an alloy, such as german silver, which consists of an admixture of copper, zinc and nickel. This alloy possesses the advantage that, for equal sizes and lengths of wire, its resistance is from ten to fifteen times greater than that of copper, and thus, to obtain a definite resistance in german silver wire of given diameter, its length would be ten to fifteen times less than if copper is employed. Moreover, its resistance is far less affected by temperature than any pure metal.

32. Substances whose electric resistance is low, such as the metals, are called *electric conductors*. Those whose electric resistance is very high, such as glass, hard rubber, and porcelain, are called *non-conductors* or *insulators*. The conducting power of a substance is determined by its resistance, and the higher the resistance the lower the conducting power.

The resistance of insulating substances diminishes with temperature. Thus a sample of glass, which, at the temperature of melting ice, had about 635 millions of millions of millions of times the resistance of copper, at the normal boiling temperature of water (212°F.) was found to have only 2600 millions of millions of times the resistance of copper.

33. All forms of matter, solid, liquid or gaseous, offer resistance to the passage of an electric current. As a rule the resistance of metals is lower than

the resistance of liquids, and the resistance of liquids, lower than the resistance of insulating solids. The resistance of gases, at ordinary pressures, is so high, that is, their insulation is so good, that it has never been measured. Moreover, whenever a current does pass through a gas it is always by means of a disruptive discharge, the nature of which will be later considered.

34. When it is desired to obtain a fixed standard resistance of definite value, say, for example, that of one ohm, it is usually made from a specially pre-

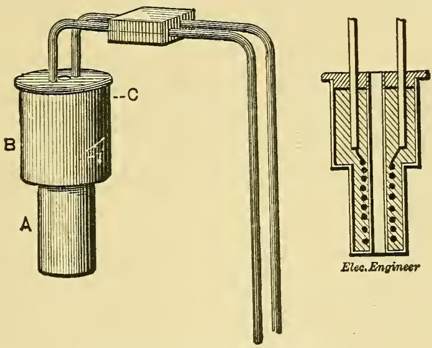


Fig. 5.—Standard Ohm.

pared alloy of platinum and silver. Fig. 5 shows the ordinary form of a *standard ohm.* It consists of a coil of platinum-silver wire, wound on a suitable, hollow core. The coil occupies the position shown at A, in the figure, and the larger cylinder B, is the receptacle for the large copper rods, which are connected with the ends of the coil in A, and form the terminals of the instrument. The interior of the cylinders A and B, is then filled with melted paraffin wax. When in use the instrument is immersed in water up to the level C, and the temperature

of this water observed by placing the bulb of a thermometer in the hollow core, thus enabling the temperature of the coil within the cylinder A, to be approximately ascertained. Platinum-silver is used because it is known to be a very stable alloy of high resistance, and the effect of temperature upon its resistance is small.

Syllabus.

The narrower a pipe and the greater its length, the greater will be its resistance to the passage of water.

The thinner a wire and the greater its length, the greater will be its resistance to the flow of electricity through it.

The resistance of a conductor depends (*1.*) On its length. (*2.*) On its area of cross-section. (*3.*) on the material of which it is composed.

The standard of electric resistance is called the International ohm.

If the length of a uniform wire be doubled, its resistance will be doubled; if its length be halved, its resistance will be halved; if its area of cross-section be halved, its resistance will be doubled.

If an iron wire has the same length and cross-section as a copper wire, its resistance will be about six and a half times greater than that of the copper wire; and if of german silver, will be from 10 to 15 times greater.

The resistance of all metals increases with the temperature. The resistance of carbon diminishes with the temperature. Alloys have a higher resistance than that of the best conducting metal they contain.

The resistance of insulating substances decreases with the temperature.

WEEKLY.

No. 4. JULY 7, 1894. Price, - 10 Cents. Subscription, $3.00.

Electrical Engineering Leaflets,

—BY—

Prof. E. J. Houston, Ph. D.

AND

A. E. Kennelly, F. R. A. S.

ELEMENTARY GRADE.

ELECTRIC RESISTANCE.

35. The resistance of pure water is enormously high. In fact water is regarded by some as an insulator when chemically pure. In practice, however, the purest river or spring water contains solids or gases in solution, the presence of which greatly increases its conducting power or diminishes its resistance. The addition of a small quantity of common salt to ordinary water greatly increases its conducting power. To reduce the resistance, therefore, of a column of hydrant water, it is only necessary to add say one per cent. by weight of common salt, or bluestone, zinc sulphate or sulphuric acid. The resistance of a concentrated solution of zinc sulphate, that is, a solution containing as much of the zinc sulphate salt as it will dissolve, is about seventeen million times greater than that of copper at ordinary temperatures.

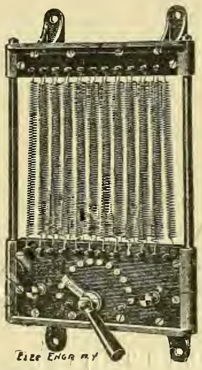
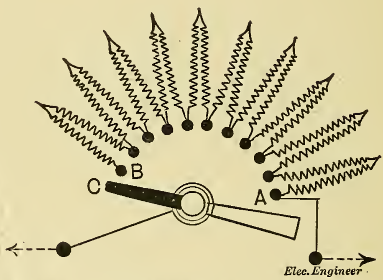
Liquids, generally, possess a fairly high resistance. Mercury, however, being a metal, forms a marked ex-

Published by
THE ELECTRICAL ENGINEER,
203 Broadway, New York, N. Y.

[Entered as second-class matter at the New York, N. Y., Post Office, June 14, 1894.]

ception to this rule, and although it has about 62 times the resistance of copper, is nevertheless a far better conductor than ordinary aqueous solutions.

36. An adjustable resistance, that is, as already described, a resistance whose value can be readily adjusted, may be so constructed that this variation is obtained manually by an attendant or automatically, as by an electromagnet. Fig. 6 shows a form of rheostat intended to carry a current capable of supplying six,

Figs. 6 and 7.—Resistance Frame and Diagram of Connections.

ordinary 16-candle power lamps without overheating. It consists as shown of loose open spirals of iron wire, or some suitable alloy, mounted on a metal frame with insulating supports, and so connected, as indicated in the diagram, Fig. 7, that the position of the lever determines the number of spirals, and consequently the resistance, added to or removed from the circuit. When the metal tongue of the lever rests on the button A, all the resistance is cut out, and the current passes directly from one terminal to the other. When the tongue rests on the

last button B, all the spirals are included in the circuit, and when, as shown, the tongue rests at C, the circuit is opened or disconnected.

37. Where higher resistances are required and the current passing through them is not very strong, caroon blocks or cylinders are frequently employed. Such a pile forms a variable high resistance whose amount is controlled by pressure. An increase of mechanical pressure greatly decreases the resistance. The high resistance of such a carbon pile is due mainly to the fact that the surfaces of adjacent carbon cylinders touch in but few points and are mainly separated by films of air. On an increase of mechanical pressure the number of points of contact is increased and consequently the resistance of the pile is decreased. A similar principle is used in the transmitting instrument of most telephones, the resistance of the carbon transmitter being varied by the to-and-fro motions of the transmitting diaphram under the influence of the speaker's voice.

38. It is sometimes necessary to know accurately the resistance of a coil or conductor in ohms. In such cases this is accomplished by the use of a special arrangement of adjustable resistances called a *Wheatstone bridge*, or *Wheatstone balance*.

The construction and arrangement of a Wheatstone bridge is shown in Figs. 8 and 9. There are twenty-two resistance coils inside the box, the ends of each of which are connected to two brass pieces as shown in Fig. 9. Between the ends of the adjacent brass pieces are the conical spaces s, into which a conical brass plug or key with an insulating handle can be pressed by hand.

When the plug fills the hole, the current passing through the instrument passes directly from one brass piece to the other, from E to E, in the figure, through the metal

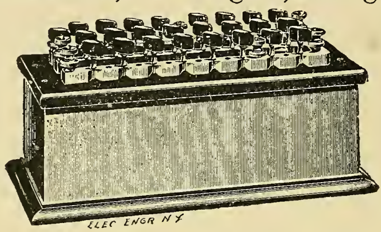


Fig. 8.—Wheatstone Bridge.

body of the plug, and the coil is said to be practically cut-out from the circuit, that is, *short-circuited.* The lowest resistance coil in the box has precisely one ohm, and the highest resistance coil has five thousand ohms, so that by pulling out suitable plugs (*unplugging*), any desired number of ohms from one up to 10,000 can be included in the circuit. The upper row has two sets of balancing resistances usually called the *arms* of the balance, one on each side of the binding post *q*. By

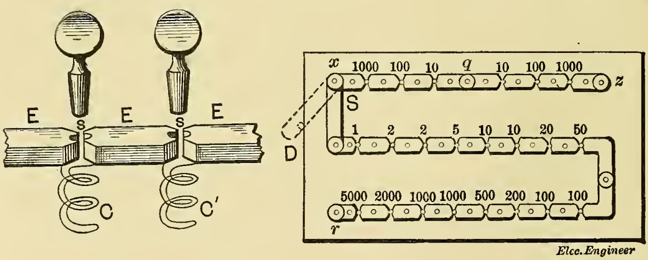


Fig. 9.—Diagram of Construction of Resistances in Bridge.

means of this instrument any unknown resistance, such as that of a line of wire or a coil, can be measured by balancing it against the known resistance unplugged in the box.

39. The resistance of a line of wire may be much greater than would be expected from its length at the above rates per mile, if the joints in the wire are electrically imperfect. The only means of securing a permanently good joint in a conducting line is by uniting in some effective mechanical manner the cleaned ends of the wire, and soldering the connection so made. The influence of the solder is to provide a complete metallic union between the ends of the wire and to prevent rusting or corrosion by excluding moist air. Some forms of joints for overhead wires are shown in Fig. 10. No. 1, is the American twist joint or Western Union joint. No. 2, is the Britannia joint. No. 3, is the McIntire

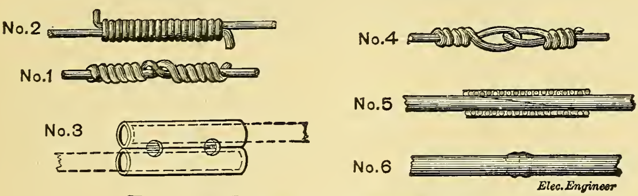


FIG. 10.—FORMS OF TELEGRAPH JOINTS.

sleeve joint into which solder is run after the wires have been pushed in from opposite sides. No. 4, is a bell-hanger's joint and should never be used. No. 5, is the section of a soldered scarf joint which has received a wrapping of wire, which is also soldered. No. 6 is a butt or end-to-end joint, which can only be made by electric welding. In all of these cases except the welded joint, solder should be run through the joint to make it permanently effective. The bell-hanger's joint although good for the purpose of mechanically ringing a bell, is very inferior for electrical purposes, for the reason that

it only brings the wires in contact over a very small surface, and this surface is apt to be impaired by oxidation.

In order that solder shall readily adhere to metal surfaces, they must be cleansed from any film of oxide or other impurity by the aid of a suitable flux. The commonest fluxes are a solution of chloride of zinc in water, powdered rosin, and powdered borax. Chloride of zinc is the most easily used, but it should not be employed in jointing wires of high grade apparatus, as, for example, high tension dynamo armatures, or joints in the machinery of arc lamps, unless carefully washed off with a solution of ammonia in water, since chloride of zinc absorbs moisture from the air, and may, therefore, become moist again after it has dried, and corrode the joint by oxidation, besides tending to destroy the insulation.

40. We have seen that the resistance of a mile of No. 7 A. W. G. copper wire is only 2.62 ohms and consequently a thousand miles of such wire would have a resistance of but 2620 ohms. One foot of such wire has only 0.0005 ohm, that is, $\frac{1}{2000}$th ohm; and an inch of this wire would only have 0.000042 ohm resistance.

It is convenient in referring to small decimals of an ohm, to use the prefixes micro- or bicro-. A microhm means the one millionth ($\frac{1}{1,000,000}$th), and the bicrohm means the one billionth ($\frac{1}{1,000,000,000}$th) of an ohm. Thus we have seen that one inch of No. 7 A. W. G. copper wire has a resistance of 0.000042 ohm or 42 microhms.

Copper, however, belongs to a class of bodies known as conductors. Insulating substances have such high resistance, that a foot of guttapercha rod, having the same diameter as No. 7 copper wire would offer a resist-

ance of about 200,000,000,000,000,000 ohms. From the inconvenient size of so large a number it is useful to employ prefixes to the ohm for representing multiples of it. Thus, mega-, one million times (1,000,000), megohm one million ohms; bega-, one billion times (1,000,000,000), begohm one billion ohms; trega-, one trillion times, (1,000,000,000,000), tregohm one trillion ohms; quega-, one quadrillion times (1,000,000,000,000,000), quegohm one quadrillion ohms.

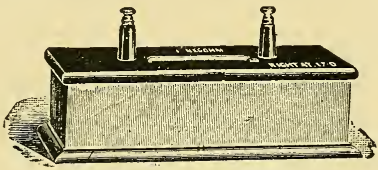


Fig. 11.—Standard Megohm.

Applying these prefixes to the resistance of the one foot of gutta-percha rod just considered we have,

200,000,000,000,000,000	ohms,
200,000,000,000	megohms,
200,000,000	begohms,
200,000	tregohms,
200	quegohms,

from which the advantage of the prefixes for very high resistances will be evident.

41. Fig. 11 shows the form, generally given to a standard resistance of one megohm, made of very fine wire. A thermometer with its scale on the surface of the box, has its bulb in the interior, by which the temperature of the coils can be estimated. The insulation of the whole apparatus has to be carefully maintained, since surface leakage might largely and unduly increase the current that would pass through so high a resistance.

Syllabus.

Water when pure has so high a resistance that it may be practically regarded as an insulator.

River or well water, owing to slight impurities, has a much lower resistance.

The addition of a small quantity of some salt to common water will greatly lower its resistance.

A pile of carbon plates will provide an adjustable high resistance. The resistance of such a column is diminished by pressure.

The Wheatstone bridge or balance is a device for the ready measurement or comparison of resistances.

By joint resistance is meant the combined resistance of two or more conductors connected in parallel.

Arc lamps are usually connected in series, and incandescent lamps in parallel.

The calculated resistance of a line wire or conductor may be greatly and unduly increased by badly constructed joints.

Properly soldered joints are always to be preferred, since the solder prevents the oxidation of the contact surfaces which would otherwise be inevitable after a time.

The following prefixes are employed; micro-, one millionth; bicro-, one billionth; mega-, one million times; bega-, one billion times; trega-, one trillion times; quega-, one quadrillion times.

Laboratory of Houston & Kennelly,
Philadelphia.

WEEKLY.

No. 5. JULY 14, 1894. Price, - 10 Cents. Subscription, $3.00.

Electrical Engineering Leaflets,

—BY—

Prof. E. J. Houston, Ph. D.

AND

A. E. Kennelly, F. R. A. S.

ELEMENTARY GRADE

ELECTRIC RESISTANCE

---

42. In calculating the resistance of a mile of copper wire, the wire was supposed not to rest on any supports, and, since 5,280 feet equal one mile, the resistance was assumed to be 5,280 times the resistance of a single foot.

We have already seen that in the case of any working circuit, the current is assumed to leave the electric source at its positive pole and, after having passed through the circuit, to re-enter the source at its negative pole. This assumes the presence of a continuous metallic conducting wire throughout the circuit. Such in point of fact are all arc and incandescent lighting and motor circuits. Such circuits are called *metallic circuits*, because they are metallic throughout. Such too are the better class of telephone circuits. For economy, all telegraphic circuits, instead of having a metallic return, use the ground to complete the circuit and are said to have ground returns.

Published by
THE ELECTRICAL ENGINEER,
203 Broadway, New York, N. Y.

[Entered as second-class matter at the New York, N. Y., Post Office, June 14, 1894.]

In calculating the resistance of a telegraphic circuit, the resistance consists of two distinct portions; namely, the metallic portion of the circuit or line and the apparatus connected therewith, and that of the earth or ground between the two ends of the line.

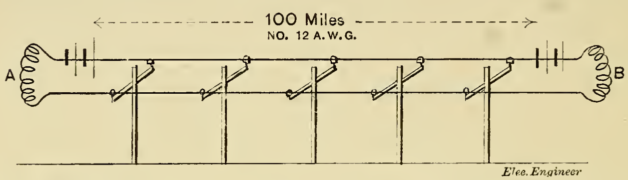


FIG. 12.—METALLIC CIRCUIT; RESISTANCE 1674 OHMS, EXCLUSIVE OF APPARATUS AT A AND B.

For example, suppose the two telegraphic stations A and B, Fig. 12, to be 100 miles apart, and connected by a metallic circuit consisting of No. 12 A. W. G. copper wire; then, omitting the resistance of batteries and instruments, the resistance in the circuit, that is, the line resistance, would be that of 200 miles of this wire, or 200×8.37, that is, 1674 ohms.

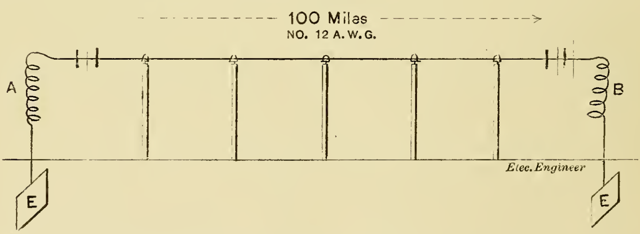


FIG. 13.—GROUND RETURN CIRCUIT; RESISTANCE OF CIRCUIT 837 OHMS, EXCLUSIVE OF APPARATUS AT A AND B.

The following table gives the resistance in ohms per mile of the most important sizes of copper and iron wire A. W. G. at 68° F.

Gauge No.	Diameter Inch.	Copper Ohms per mile.	Iron Ohms per mile.
0000	0.460	0.258	1.7
000	0.4096	0.326	2.1
00	0.3648	0.411	2.7
0	0.3249	0.518	3.4
1	0.2893	0.653	4.3
2	0.2576	0.824	5.4
3	0.2294	1.039	6.8
4	0.2043	1.31	8.6
5	0.1819	1.65	10.8
6	0.1620	2.08	13.6
7	0.1443	2.63	17.3
8	0.1285	3.31	21.7
9	0.1144	4.18	27.4
10	0.1019	5.27	34.6
11	0.09074	6.64	43.5
12	0.08081	8.37	54.9

These resistances are for copper wire of standard conductivity. They are only approximate for the iron wires, since different samples of iron differ considerably in their resistance.

43. But suppose these stations, instead of being provided with a metallic circuit, have a ground-return circuit arranged as shown in Fig. 13, where a single wire is stretched from A to B, and its free ends connected through batteries and apparatus to ground plates E and E, or iron pipes deeply buried in moist soil. Here, omitting the resistance of instruments and batteries as before, the total resistance of the circuit consists of two parts, namely, the resistance of 100 miles of No. 12 A. W. G. copper wire or 837 ohms, and the resistance of the ground between the two stations. Where large plates are employed in permanently moist earth, the resistance of the ground in the circuit may be as low as

a fraction of an ohm. In some localities, however, especially where the soil is permanently dry, it is difficult to obtain a good ground connection, and the resistance of the ground circuit, in such a case, may be hundreds of ohms.

44. Telegraph wires are bare uncovered wires of iron or copper, and are prevented from coming in contact with the ground by being supported on *insulators*. The insulators are supported on arms, and are made in various forms from some non-conducting substance, such as glass, hard rubber, earthenware, or porcelain. The line wire is so fastened to the insulator, that to escape from the wire, the current would have to pass through the body of the insulator to the ground. Although under these circumstances the resistance of a single glass insulator would be about 500 begohms, yet in practice the resistance of a single insulator is much less than this, say, 250 megohms. This is due to the leakage over the surface of the insulator through a film of moist dust or dirt.

45. In a mile of telegraph line, there are usually about forty poles. The line wire will, therefore, rest on forty insulators in this distance. Were these forty insulators so placed that there existed but a single path to the ground through each in succession, their insulating power would be forty times that of a single insulator, and if each has singly a resistance of 250 megohms, the total insulation resistance would be 40 times as much, or ten begohms. But, in fact, forty separate paths to ground, afford forty separate places for leakage; hence the leakage on a mile of wire is forty times greater than

over a single insulator. This will explain the fact that the insulation resistance of a telegraph line diminishes as the length of the line increases.

Various forms are given to telegraph insulators, some of which are shown in Fig. 14. However different the shape, the intention is to secure a long and a narrow path of leakage surface between the wire and the pin upon which the insulator is supported.

46. Conductors placed indoors should always be insulated and never run bare. A good insulating material for such purpose should be fire-proof, water-proof,

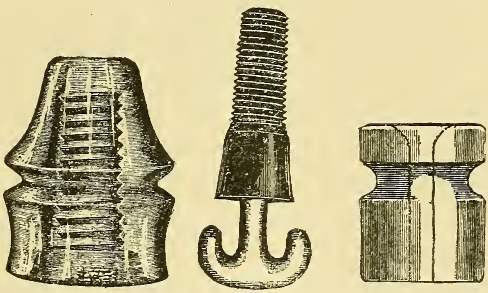


Fig. 14.—Various Forms of Telegraph Insulators.

and incombustible. These properties become more essential as the electrical pressure or voltage to which the wires are subjected is increased. A low degree of insulation is secured by a covering of cotton, a better degree by a covering of silk. These coverings may be single or double, and may be layed, wrapped or woven on the wire. For a higher degree of insulation the wrapped or covered wires are immersed in melted paraffin, wax, or shellac varnish. Very high insulation is obtained by suitable applications of such insulating substances as

gutta-percha, caoutchouc, kerite, etc. Where exposed to moisture a cotton or silk covered wire should not be employed unless when coated in addition with some water-proof material.

47. For underground conductors where the wire is buried directly in the earth, some form of lead covered cable or iron tubing enclosing insulated wires is generally employed. The object of the metallic covering or sheath, that is, the lead or the iron, is threefold.

(*1.*) To protect the conductors from mechanical injury or abrasion.

(*2.*) To protect the cable from water.

(*3.*) To protect the conductor from the disturbing effects of electrostatic induction in a manner which will be described in a subsequent leaflet.

48. It is generally found most convenient in practice, especially in cities where it is desirable to have ready access to the cables, to place them in conduits or subways, in which case a metallic sheath, while advisable, is not absolutely necessary. Where conduits are employed, *manholes* or *junction boxes* are situated at convenient distances apart for drawing in the length of cable, connecting them up or testing them. Where subways are used such junction boxes are unnecessary.

Where the cable is to be employed under water, for short distances, such as for river crossings, a well formed covered cable may be used. Where extended distances have to be covered, such as gulfs or oceans, a gutta-percha covered cable is employed. In such cases the sheathing is particularly strong, and is composed of iron wires wrapped on.

49. In a telegraph line wire the current can escape to ground only at the insulators, and in a mile of wire this would be forty points of escape. In a cable buried in the earth or submerged in water a leakage path is offered through the sheathing to ground over the entire surface of the conductor. Consequently, in such cases, the insulation of the conductor increases markedly with the thickness of the insulating coating or cover. The insulation resistance of a well insulated cable may vary from 200 to 20,000 megohms per mile, according to the nature, dimensions and temperature of the insulating cover. This would be in the latter case,

$$\left.\begin{array}{ll} 105{,}600{,}000 & \text{megohms} \\ \text{or } 105{,}600 & \text{begohms} \\ \text{or } 105.6 & \text{tregohms} \end{array}\right\} \text{per foot.}$$

50. We have stated that the resistance of a conductor for a given character of material depends upon the area of cross-section of the conductor. It is evident that this area of cross-section is independent of the shape of the conductor, so that two wires of copper of the same weight, each one foot long, but one of round and the other of square cross-section would have the same resistance, since they must necessarily have the same cross-sectional area. When, however, the current in a conductor is not steady, but is rapidly increasing or diminishing, then the shape of the cross-section does influence the apparent resistance of the conductor for reasons that will be subsequently explained. Since a lightning discharge consists of very rapidly varying currents, there is an advantage in employing a flat ribbon rather than a round rod; or a stranded conductor, rather than a single large wire.

51. The following table gives a list of resistances that frequently occur in practical applications.

Telegraphic sounders, ...	1 to 10 ohms.
Telegraphic Western Union relay	15 to 500 ohms, usually 150.
A Bell telephone	75 ohms.
A telephone call bell...........	80 ohms.
An ordinary incandescent lamp of sixteen candle power	283 ohms, hot; about 560 ohms, cold.
Insulation resistance of a mile of telegraph wire	500,000 ohms to 5000 megohms.

Syllabus.

In a metallic circuit, the current passes from the positive to the negative pole of the electric source entirely through metal.

In a grounded circuit, the return path is through the ground.

The resistance of a ground return circuit between any two points, exclusive of apparatus, is appromimately half the resistance of the metallic circuit between the same points, the resistance of the ground being generally very small.

In practice the resistance of a telegraph line insulator is not the resistance of the body of the non-conducting material, but the much smaller resistance of the film of moist dust or dirt on its surface.

The insulation resistance of a telegraph line is smaller, the greater the number of insulators supporting it.

Some form of metal-covered cable is generally used for underground conductors.

Submarine cables generally employ a gutta-percha covered conductor provided with a sheathing of galvanized iron wires.

Laboratory of Houston & Kennelly,
Philadelphia.

WEEKLY.

No. 6. JULY 21, 1894. Price, - 10 Cents. Subscription, $3.00.

Electrical Engineering Leaflets,

—BY—

Prof. E. J. Houston, Ph. D.

AND

A. E. Kennelly, F. R. A. S.

ELEMENTARY GRADE

ELECTRIC CURRENT.

52. Nearly all the important effects produced by electricity are not the direct results of electric pressure or electromotive force, but are phenomena which attend electric flow or current. For example, the light of an incandescent lamp is the result due to the passage of electricity through the carbon filament. The rotation of an electric motor is the result of an electric current passing through the machine. The to-and-fro motions of a telegraph sounder armature are due to the action of an intermittent electric current passing through the coils of the instrument. The telephone operates by the vibrations of its diaphragm caused by the varying electric current passing through its coil. The heat in the electric heater is a result due to the current passing through the device. The deposition of metal in electroplating is due to the current passing through the bath. The convulsive muscular movements accompanying electric shocks are due to the passage of an electric current

Published by
THE ELECTRICAL ENGINEER,
203 Broadway, New York, N. Y.

[Entered as second-class matter at the New York, N. Y., Post Office, June 14, 1894.]

through the body. The phenomena of thunder and lightning are due to the passage of an electric discharge between two clouds, or between a cloud and the earth, and the passage of such a discharge constitutes a temporary electric current.

53. The quantity of water which escapes from a reservoir through an outlet pipe at the base, depends upon the area of cross-section of the pipe and the velocity with which the water flows through it. This velocity, for a given size of pipe, depends upon the depth of the water in the reservoir. Roughly speaking, if we know the area of cross-section of the pipe in square

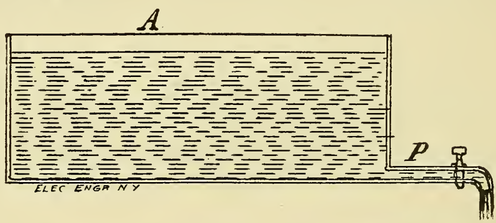


FIG. 15.—RESERVOIR OF WATER WITH OUTFLOW PIPE AT P.

inches, and the velocity with which the water moves through the pipe in inches per second, then the flow, or the quantity of water in cubic inches which escapes from the reservoir in a second, will be obtained by multiplying the area of the pipe by the velocity of movement in the water.

Thus, if the water in the reservoir A, Fig. 15, is moving through the outlet pipe P, whose area of cross-section is two square inches, with a velocity of 100 inches per second, then 200 cubic inches of water would flow through the pipe and escape from the reservoir in every second of time.

Other things being equal, the velocity with which the water will move through the pipe will depend upon the depth of water in the reservoir A; that is, upon the pressure which the water will exert at the pipe P. If, now, the depth of water in the reservoir A, be increased, and with it the pressure, until the velocity of flow through the pipe be doubled, namely, to 200 inches per second, then the flow will be 400 cubic inches per second.

Suppose now the velocity remains 200 inches per second and the cross-section be doubled, the quantity of water per second which passes through the pipe will be 800 cubic inches, that is to say, as the area of cross-section of the pipe increases, so the quantity of water per second under the same pressure is increased.

54. In order to obtain practical ideas concerning the electric current, it is convenient to compare it with the flow of water through a pipe. In the case of water, the flow is rated by the quantity-per-second which passes through the pipe. If we assume that the unit of quantity is a cubic inch, then we speak of a flow of so many cubic inches per second.

Similarly in the case of electricity, the flow is rated by the quantity of electricity per second which passes through the conductor. Although we cannot see electricity, we are forced to assume that in order to produce its phenomena, a certain quantity must pass through a circuit in a given time, and the unit quantity of electricity is called the *International coulomb*, after Charles A. Coulomb, a distinguished French electrician; and, just as we speak of a current of liquid as being so many cubic inches per second, so we speak of a current of

electricity as being so many coulombs per second; and the unit of current, or one coulomb per second, is called the *International ampere*, after Ampère, another distinguished French electrician. Thus, when we speak of a current of a given number of amperes, we mean that number of coulombs passing through the circuit per second. Just as a cubic inch of water is a perfectly definite quantity of water, so a coulomb of electricity is a perfectly definite quantity of electricity, and, although we cannot see a coulomb, yet we can rigorously measure it by its effects. For example:

One coulomb of electricity passing through water, will decompose the water, and liberate about $\frac{1}{87}$th cubic inch of the mixed constituent gases, oxygen and hydrogen, at the ordinary temperature and pressure.

A coulomb of electricity, will, when passing through a copper plating bath, deposit $\frac{1}{1,383,350}$ pound of copper; therefore 1,383,350 coulombs will deposit one pound of copper. Similarly 405,740 coulombs will deposit one pound of silver.

An ordinary 16-candle power 110-volt incandescent lamp requires a current of about half an ampere, or a half coulomb per second. If now this lamp be kept burning for 24 hours, 43,200 coulombs of electricity will have passed through it during this time; $\frac{1}{2} \times 60 \times 60 \times 24 = 43,200$. Again, since we have seen that 1,383,350 coulombs will deposit one pound of copper in a plating bath, and since one coulomb per second is an ampere, one ampere will deposit the pound of copper in 1,383,350 seconds or 384.3 hours. Two amperes would deposit the same amount of metal in half the time.

55. If a current of one ampere be maintained steadily in a circuit for one hour, the quantity of electricity which passes in this time is called an *ampere-hour* and is equal to 3600 coulombs (60×60). An ampere-hour, therefore, can produce electrolytic effects to the extent of 3600 coulombs. Thus we have seen that the pound of copper requires 1,383,350 coulombs for its deposition; it will, therefore, take $\frac{1383350}{3600} =$ 384.3 ampere-hours.

56. Electric currents may be conveniently divided into three general classes. (*1.*) *Continuous* currents. (*2.*) *Pulsatory* currents. (*3.*) *Alternating* currents.

A continuous current is one in which electricity flows at a uniform rate and in the same direction. Such a current is usually supplied by voltaic cells or storage cells. Continuous currents are employed for electroplating.

A pulsatory current is one in which electricity flows in the same direction but at a variable rate. Pulsatory currents are employed in the ordinary methods of telegraphy. They are produced by many arc light dynamos; and, strictly speaking, by nearly all dynamo-electric machines. It most cases, however, the pulsations are so slight that their currents may practically be regarded as continuous.

An alternating current is one in which electricity flows alternately in opposite directions, and generally at a variable rate. Alternating currents are largely used in arc and incandescent systems of lighting, and in the electric transmission of power.

57. The presence of an electric current passing through a conductor may be manifested in a variety of ways, its existence being indicated by causing the current to produce one or another of its characteristic effects. For example, its heating effects, its chemical effect, or its magnetic effects. The magnetic effects are those most generally employed, the current being observed by the movement of a magnetic needle or coil of wire under the influence of the current.

An instrument which simply indicates, and does not measure the current strength passing is called a *galvanoscope*, but when it measures the current strength it is called

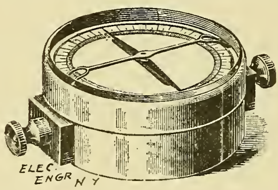


Fig. 16 —Simple Form of Galvanoscope.

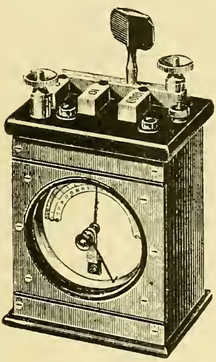
a *galvanometer*, *amperemeter*, or *ammeter*. Ammeters are constructed in a variety of forms, and may be divided into classes according to their methods of operation.

Fig. 16 shows a simple form of galvanoscope ; for, this instrument although provided with a divided scale, is not calibrated to show amperes. Here the current passing through a coil of wire within the instrument, causes the needle to deflect. Reversing the direction of the current reverses the direction of deflection.

Fig. 17 shows a form of galvanoscope suitable for battery testing. Here the needle is vertical.

Fig. 18 shows a common form of D'Arsonval galvano-

meter. Here a movable coil A B, of many turns of insulated wire is supported on a torsion wire, between the poles of a vertical, permanent magnet. The torsion wire carries the current to be measured into and out of the coil. The amount of movement of the coil, when the current passes through it, is determined by the movement of a spot of light reflected from the mirror C, upon a suitably placed scale in front of the instrument.



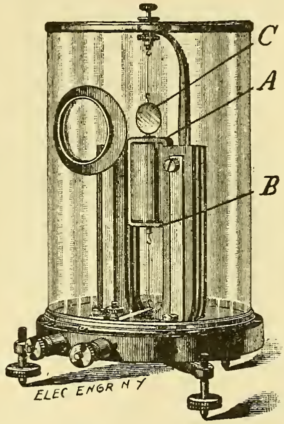


FIG. 17.—FORM OF GALVANOSCOPE FOR BATTERY TESTING.

FIG. 18.—D'ARSONVAL GALVANOMETER.

The value of this instrument lies in the fact that it can be used near dynamos, being only very slightly influenced by neighboring magnets.

SYLLABUS.

Nearly all electrical effects are due to the passage of an electric current.

The flow or amount of water which passes from a reservoir through a discharge pipe depends upon the cross-

section of the pipe and the velocity of water through it. If the cross-section of the pipe be doubled, the flow of water will be doubled. The flow of water through a pipe may be measured in cubic inches per second.

The flow of electricity through a conductor is measured in coulombs-per-second, or amperes.

The unit of electric flow is called the ampere, and is equal to the passage of a coulomb per second through the circuit.

The coulomb is a definite quantity of electricity, and as such is capable of producing certain definite effects, such, for example, as the deposition of $\frac{1}{1,383,350}$ of a pound of copper in a plating bath.

An ampere-hour is a quantity of electricity such as passes through a circuit with a current of one ampere maintained steadily for an hour, (or, with twelve amperes for five minutes,) so that an ampere-hour is 3600 coulombs.

Laboratory of Houston & Kennelly,
Philadelphia.

WEEKLY.

No. 7. July 28, 1894. Price, - 10 Cents. Subscription, $3.00.

Electrical Engineering Leaflets,

—BY—

Prof. E. J. Houston, Ph. D.
AND
A. E. Kennelly, F. R. A. S.

ELEMENTARY GRADE.

OHM'S LAW.

58. When a reservoir supplies a city with water through a long pipe or aqueduct, the quantity of water discharged through the pipe per second, depends not only upon the length and size of the pipe as already explained, but also depends upon the pressure which drives the liquid through the pipe, that is, upon the height of the water in the reservoir above the outlet of the pipe. This difference of level is called the head, and the greater the head of water, the greater the pressure, and hence the greater the discharge through the pipe.

59. Similarly in the case of an electric current flowing through a conductor, the quantity of electricity per second, or the electric current, depends on the electric pressure, or, as has been explained, the E. M. F. (See Sec. 15). As, therefore, the electromotive force in a circuit is increased, the strength of current increases. But it is not only the electromotive force acting on a cir-

Published by
THE ELECTRICAL ENGINEER,
203 Broadway, New York, N. Y.

[Entered as second-class matter at the New York, N. Y., Post Office, June 14, 1894.]

cuit which determines the current strength, the resistance of the circuit also has an effect on the current strength. In the case of the liquid already considered, the quantity of liquid per second that flows through the discharge pipe in the reservoir depends not only on the head or pressure which sets it in motion, but also on the area of cross-section of the pipe through which it is moving and the length of the pipe. The escape will be much less through a very long pipe than through a short one. In the case of the electric current, the character and dimensions of the circuit determine the amount of its resistance as already explained in Leaflet No. 3. The electromotive force and the resistance in a continuous current circuit, therefore, determine the strength of the current in that circuit.

60. If the total electromotive force in the circuit in volts is divided by the total resistance of the circuit in ohms, the quotient will express the strength of the current in amperes. This fact was first announced by Dr. Ohm of Berlin, and is known as Ohm's Law.

Ohm's law is generally expressed by the following simple symbols,

$$C = \frac{E}{R};$$

where C, is the current in amperes, flowing in a circuit; E, is the electromotive force acting in that circuit expressed in volts, and R, is the resistance of the circuit expressed in ohms. The formula reads:—The current strength is equal to the electromotive force divided by the resistance.

The formula may also, therefore, be written as follows,

$$\text{amperes} = \frac{\text{volts}}{\text{ohms}},$$

and this current strength is the same in all parts of the circuit.

61. Ohm's Law is one of the most important laws in the application of the continuous electric current to electric engineering, and in order to fully comprehend it, the student should become thoroughly familiar with it. For this purpose the following illustrations may serve.

62. Suppose a perfectly insulated telegraph circuit 150 miles in length, (Fig. 19), composed of No. 8, Brown and Sharpe galvanized iron wire with ground

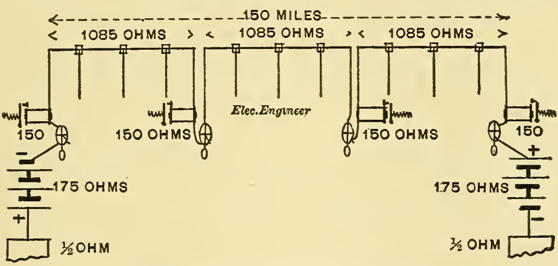


FIG. 19.—TELEGRAPH CIRCUIT SHOWING RESISTANCES.

return, to have four offices, and a relay in circuit at each office of 150 ohms resistance, also a battery at each end of the line of fifty cells, of gravity Daniell, each cell having an electromotive force of $1\frac{8}{100}$ volts and a resistance of $3\frac{1}{2}$ ohms. Required the current strength:

The resistance of 150 miles of No. 8 wire, at $21\frac{7}{10}$ ohms per mile..............	3,255
The resistance of earth connections at ends.	1.0
The resistance of four relays at 150 ohms each	600
The resistance of 100 cells at $3\frac{1}{2}$ ohms each	350
Total resistance in circuit....	4,206 ohms.

The electromotive force in the circuit will be that of 100 cells each having $1\frac{8}{100} = 108$ volts. So that the current strength in the circuit is $\frac{108}{4206} = \frac{1}{39}$th ampere.

63. If in the above circuit it became necessary to to have a current of $\frac{1}{25}$th ampere, what electromotive force would be necessary to produce this current?

To determine this by Ohm's law we take the formula, amperes $= \dfrac{\text{volts}}{\text{ohms}}$ and we transform this into the formula,

volts = amperes multiplied by ohms.

So that in the case here presented, volts $= \frac{1}{25} \times 4206 = 168$ approximately. From which it will be seen that about 156 cells each of $1\frac{8}{100}$ volts will be needed, but since each cell introduces its own internal resistance into the circuit, a slight correction will be necessary on this account.

64. Taking the number 156, or 78 cells at each end, the current in the line should be

156 cells at $1\frac{8}{100}$ volts $= 168\frac{1}{2}$ volts

Line	=	3255	ohms.
Ground circuit	=	1	"
Relays	=	600	"
156 cells at 3.5 ohms	=	546	"
		4402	"

Amperes $= 168\frac{1}{2}$ volts $\div$ 4402 ohms $= \frac{1}{26}$th ampere approximately. In practice, however, it is to be remembered that the effect of leakage of current is to increase the current near the ends of the line and diminish it in the middle as shown in Fig. 20, so that while the current leaving the batteries may be greater than the calculated amount, say $\frac{1}{20}$th ampere, the current in the middle of the line may be only $\frac{1}{50}$th ampere.

65. A continuous current dynamo has to supply a cluster of 50 16-candle-power incandescent lamps, (made to take each $\frac{45}{100}$th ampere at 110 volts pressure), at a distance of half a mile. If No. 4 B. & S. copper

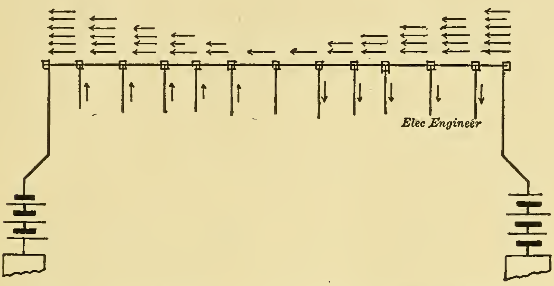


FIG. 20.—TELEGRAPH CIRCUIT SHOWING LEAKAGE.

wire is used for the conductors as in Fig. 21. What will be the pressure at dynamo terminals? The total current delivered will be $50 \times \frac{45}{100} = 22\frac{1}{2}$ amperes. The resistance in the mile of going and returning wire No. 4 B. & S. $= 1\frac{3}{10}$ths ohms.

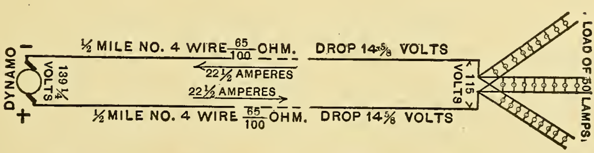


FIG. 21.—INCANDESCENT LAMP CIRCUIT, SHOWING DROP OF PRESSURE IN LINE.

Volts = amperes × ohms $= 22\frac{1}{2} \times 1\frac{3}{10} = 29\frac{1}{4}$

The total *drop* is thus $29\frac{1}{4}$ volts (the drop on each wire being half this amount or $14\frac{5}{8}$ volts) and the pressure at dynamo-terminals $= 110 + 29\frac{1}{4} = 139\frac{1}{4}$ volts.

66. If the preceding dynamos will only give 125 volts at $22\frac{1}{2}$ amperes and cannot reach $139\frac{1}{4}$ volts, what size of wire must be employed to maintain 110 volts at the lamps?

Here the total drop is $125 - 110 = 15$ volts.

$$\text{Resistance} = \frac{\text{volts}}{\text{amperes}} = \frac{15}{22\frac{1}{2}} = \frac{2}{3}\text{ ohm.}$$

The resistance of the one mile of wire is to be $\frac{2}{3}$ ohm and the nearest size of wire to this is No. 1. B. & S., $\frac{65}{100}$ ohm per mile (Leaflet No. 4.)

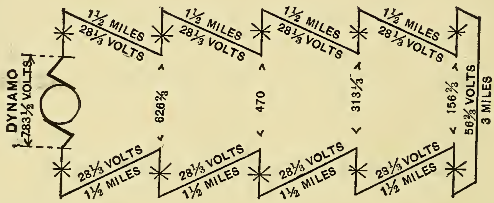


Fig. 22.—Arc Light Circuit Showing Drop in Line and Increase in Pressure Towards the Dynamo.

67. An arc circuit (See Fig. 22) is 15 miles long and is made up of 10 arc lamps each automatically regulating to 50 volts pressure when supplied with 9 amperes, The wire is No. 6 B. & S. What will be the pressure at dynamo terminals?

15 miles of No. 6 wire at $2\frac{1}{10}$ ohms per mile $= 31\frac{1}{2}$ ohms.
(Drop) Volts = amperes $\times$ ohms $= 9 \times 31\frac{1}{2} = 283\frac{1}{2}$ volts.
10 arc lamps in series of 50 volts each $= 500$ "

Total pressure at dynamo terminals, $783\frac{1}{2}$ "

The total drop in this circuit is $283\frac{1}{2}$ volts or rather more than 36 per cent. of the dynamo pressure. About

36 per cent. of all the electrical energy delivered to the line by the dynamo is therefore consumed in transmitting the current and the balance is distributed among the ten arc lamps.

68. If in the last case the resistance of the dynamo was 10 ohms, what would be in the drop in the dynamo itself, and what the total effective E. M. F. of the the dynamo?

Drop = volts = amperes × ohms = 9 × 10 = 90

Pressure at dynamo terminals	= $783\frac{1}{2}$	volts.
Drop in dynamo............	= 90	"
Total effective E. M. F. in dynamo	= $873\frac{1}{2}$	"

Syllabus.

The quantity of water discharged from a filled reservoir depends on the pressure of water at the outlet, and on the length and area of cross-section of the pipe.

The quantity of electricity flowing through a conductor from an electric source, depends on the pressure at the terminals of the conductor, and on the length and area of cross-section of the conductor.

The resistance opposing the electric current varies with the conducting power of the material of which the circuit is composed, on the length of the circuit, and on its area of cross-section; the greater the conductivity of the wire, the shorter its length, and the greater its area

of cross-section, the greater the current that a given electric pressure will deliver through the wire.

Ohm's law may be expressed as follows:—The current strength in any continuous current circuit expressed in amperes is equal to the total electric pressure in the circuit expressed in volts, divided by the total resistance expressed in ohms.

The fall of pressure in any conductor carrying a current, is commonly called the "drop" of pressure in that conductor.

Laboratory of Houston & Kennelly,
Philadelphia.

WEEKLY.

No. 8. AUGUST 4, 1894. Price, - 10 Cents. Subscription, $3.00.

Electrical Engineering Leaflets,

—BY—

Prof. E. J. Houston, Ph. D.

AND

A. E. Kennelly, F. R. A. S.

ELEMENTARY GRADE

ELECTRIC CIRCUITS.

69. We have already seen that electric sources produce electromotive forces. These electromotive forces when offered a conducting circuit produce electric currents, which manifest their presence by a variety of effects. We have also seen that these currents are assumed to leave the source at its positive pole, and after having passed through the conducting path and such electro-receptive or translating devices as may be placed therein, to re-enter the source at its negative pole. In other words, the current after leaving the positive pole of the source, passes through the external conducting path, and back to the electro-positive pole through the electromotive source, thus completing what is called an *electric circuit.*

70. All conducting circuits consist essentially of three part, viz. :

(*1.*) The electric source or sources.

(*2.*) The leads or electric conductors.

(*3.*) The translating devices operated by the current.

Published by
THE ELECTRICAL ENGINEER,
203 Broadway, New York, N. Y.

[Entered as second-class matter at the New York, N. Y., Post Office, June 14, 1894.]

These electric sources are connected with the translating devices by means of variously arranged conducting paths or circuits.

A translating device is any device traversed or actuated by a current, that is employed for the conversion of electrical energy. A great variety of translating devices have been designed to produce particular forms of electric effect, that is, to translate the electric energy of the current into light, heat, magnetic or chemical energy.

71. The purpose of an electro-receptive device is to produce the required electric effect at a distance from the electric source. In practice, all circuits are, therefore, composed of an electric source or sources, the electro-receptive device, or devices, and suitable conducting paths connecting the sources with the receptive devices. The devices are of a variety of forms, each designed to produce some definite desired effect under the influence of the electric current.

72. We have already called attention to the fact that work is never done without an expenditure of energy. Some form of energy is expended in producing the electric activity of the source. This electric activity is expended in producing characteristic effects in the conducting paths, and receptive devices. Moreover, an exact relation exists between the amount of energy expended in the electro-receptive device and the amount of work done by the device. That is to say, if an electric motor works with an activity of one horse-power, electric energy to the extent of rather more than one horse-power is expended in and absorbed by the motor; and, in the case of the motor working under definite

conditions, the amount of this excess would be invariable. In the case of an incandescent lamp a definite relation exists between the expenditure of energy in the lamp and the amount of light produced, and it is found that a horse-power, all expended electrically in incandescent lamps, is capable of producing a certain number of candle-power, usually about 240.

73. Translating or receptive devices may be conveniently grouped into the following classes, viz.:

TRANSLATING OR RECEPTIVE DEVICES.

- 1. Magnetic.
  - (1.) Electro-magnets.
  - (2.) Motors.
  - (3.) Electromagnetic signalling apparatus.
  - (4.) Telegraphic and telephonic apparatus.
  - (5.) Telpherage systems.
  - (6.) Transformers.
- 2. Thermal.
  - (1.) Arc or incandescent light lamps.
  - (2.) Electric heaters.
  - (3.) Electric welders.
- 3. Chemical.
  - (1.) Plating baths.
  - (2.) Uncharged storage cells.

74. The electric circuits or conducting paths by means of which the electric sources are connected with the translating device, are of various forms. They may conveniently be arranged under four main classes, viz.:

(*1.*) Series circuits.
(*2.*) Multiple or parallel circuits.
(*3.*) Multiple-series circuits.
(*4.*) Series-multiple circuits.

75. In the series circuit, more than a single electro-receptive device is employed in a single path, and the separate devices are so placed in the circuit, that the

current passes through each successively before finally returning to the source. Arc lights and telegraph relays are usually operated in series circuits, as shown in Fig. 23, in which eight arc lights are represented working in series circuit from the dynamo, D. The current leaving the dynamo at the positive pole, as indicated by the arrow, passes through the upper carbon of the lamp, a, and, leaving the lower carbon, passes through the conducting line to the upper carbon of the next lamp through which it passes as before, and, leaving its lower carbon, passes then successively through the lamps, c,

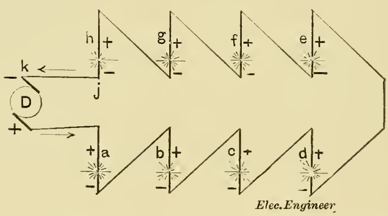


FIG. 23.—SERIES CIRCUIT OF EIGHT ARC LAMPS.

and d, in the same direction, finally returning to the source through the conductor, $j\ k$.

In general a series circuit requires to be operated by a constant current, and since the current strength depends upon the electromotive force and the resistance $\left(C=\frac{E}{R}\right)$, it is evident that as extra lamps are inserted in, or removed from the series circuit, the electromotive force of the dynamo, D, must be varied accordingly. A 50-arc light dynamo must, therefore, be capable of supplying an E. M. F. of about 2,500 volts, and must reduce this E. M. F. as the arc lights are removed from its circuit.

76. Sources may also be connected in series. In this case the positive pole of one source is connected with the negative pole of the succeeding source, and so on throughout the series. Fig. 24, represents three Leclanché cells connected in series. Here the carbon plate is the positive pole of the cell, and the zinc plate the negative pole.

A number of separate sources connected so as to form a single source is called a *battery*, and, in a series connection, the electromotive force is the sum of the separate electromotive forces, while the resistance of the battery is the sum of the separate resistances of the sources. If the cells shown in the figure have each an E. M. F. of one

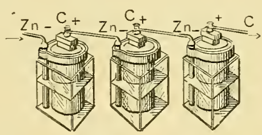


FIG. 24.—SERIES OF THREE LECLANCHE CELLS.

and a half volts, and a resistance of one ohm, the battery will have four and a half volts E. M. F. and three ohms resistance.

77. In the multiple circuit more than one electro-receptive device is employed in the circuit. Conductors or leads are connected to the positive and negative terminals respectively of the source. The receptive devices have their positive poles connected with the positive leads and their negative poles connected with the negative leads, so that the current branches, or subdivides, through the additional paths so provided, bridged between the positive and negative leads. Fig. 25 represents four incandescent lamps operated in

parallel. Here the current leaving the dynamo D, at the positive lead, passes along the lead to the point where it branches, part flowing through the lamp (1),

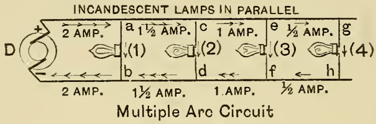


Fig. 25.

and returning to the dynamo by the negative lead between *b*, and the dynamo, while the remainder and larger part passes along the positive lead to *c*. At *c*, the current again divides, part going through the lamp (2) and returning to the dynamo as shown, and the other part passing along the positive lead between *c* and *e*, again branching and dividing at *e*, passing through the lamp (3) and returning to the dynamo, the remainder proceding to *g*, and so on.

78. Electric sources may also be connected in parallel. Fig. 26 represents three Bunsen cells connected in parallel. Here the three carbons are connected to the positive terminal A, and the three zincs to the single negative terminal B.

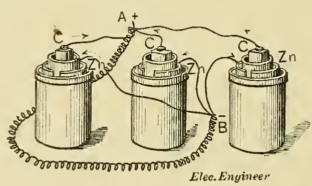


Fig. 26.—Battery of Three Bunsen Cells Connected in Multiple.

In a battery of multiply-connected sources, the total electromotive force is that of a single source, while the resistance of such a battery is as many times less than

the resistance of a single source as there are sources in multiple. Thus if each of the three cells in the figure has an E. M. F. of two volts, and a resistance of one ohm, the E. M. F. of the battery will be two volts, and its resistance one-third ohm.

79. In the multiple-series circuit, the receptive devices are connected in separate groups in series, and these groups subsequently connected in multiple. Thus in Fig. 27, the six arc lamps are connected in three separate series groups of two, and these three groups connected in parallel to the positive and negative leads from the dynamo D. Since an arc lamp requires about fifty volts

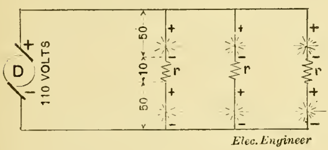


FIG. 27.—MULTIPLE-SERIES CIRCUIT. THREE SERIES OF TWO ARC LAMPS EACH, IN MULTIPLE.

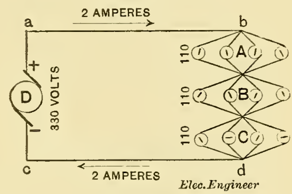


FIG. 28.—SERIES-MULTIPLE CIRCUIT. THREE GROUPS OF INCANDESCENT LAMPS IN SERIES.

to operate it, when connected with an incandescent dynamo designed to give say 110 volts as shown, it is customary to connect the two arc-lamps in series to its mains with the addition of a small resistance *r*. This arrangement is called a multiple-series, because, as will be seen, it consists of a multiple of series circuits.

80. In the series-multiple circuit, a number of electro-receptive devices are connected in separate groups in multiple and these groups subsequently connected in series. Thus in (Fig. 28) the current from the dynamo D, passes through the lead *a b*, and flows through

the multiple group A, of incandescent lamps in parallel, subsequently through the multiple group B, connected in series with A, and finally through the multiple group C as indicated.

If each lamp requires to be supplied with half an ampere, at 110 volts pressure, then for the 12 lamps shown in (Fig. 28), only two amperes are required to flow through the main conductors *a b*, and *c d*; whereas if all the lamps had been connected in parallel with a 110 volt dynamo as shown in (Fig. 25), the current leaving the dynamo would have been six amperes, and the conductors, for the same drop in pressure, would have been necessarily three times heavier or larger in cross-section. For this reason the series-multiple system with slight modification is usefully employed in *three-wire systems.*

SYLLABUS.

All working circuits consist of three parts. (*1.*) The electric source or sources. (*2.*) The leads or electric conductors. (*3.*) The translating devices.

The electric energy delivered by a source is expended in the translating device in producing that electric effect which the device is designed to furnish.

Translating devices may be divided into three groups, viz: magnetic, thermal and chemical. Electric circuits may be conveniently divided into series, multiple, multiple-series and series-multiple.

In a series circuit, the resistance is equal to the sum of the separate resistances, and in a multiple circuit supplying devices of equal resistance, the total resistance of the devices in the resistance of a single device divided by the number of devices.

Laboratory of Houston & Kennelly,
Philadelphia.

WEEKLY.

No. 9. AUGUST 11, 1894. Price, - 10 Cents. Subscription, $3.00.

Electrical Engineering Leaflets,

—BY—

Prof. E. J. Houston, Ph. D.

AND

A. E. Kennelly, F. R. A. S.

ELEMENTARY GRADE

THE VOLTAIC CELL.

81. As we have already seen, the contact of dissimilar substances is unvariably attended with the production of an electric charge, and the discharge of such bodies produces a momentary electric current. In order to render this current approximately continuous, the contact must be frequently renewed, and this, as we have seen, is accomplished by the friction of the surfaces. Here the source of the electric energy is clearly to be traced to the energy expended in producing the friction between the two surfaces. Electrification by friction occurs, as we have seen, even if one of the bodies rubbed is a conductor.

82. If two metallic conducting surfaces are brought into contact, when surrounded by a conducting liquid, a continuous flow of electricity will result. One, at least, of the conducting metals will be chemically attacked, and a part of the liquid will be decomposed.

Published by
THE ELECTRICAL ENGINEER,
203 Broadway, New York, N. Y.

[Entered as second-class matter at the New York, N. Y., Post Office, June 14, 1894.]

Here the source of the electrical energy may be traced to the chemical action of the liquid on the plates.

Any combination of parts whereby electricity can be produced in this manner by chemical action is termed a *voltaic cell.* The voltaic cell takes its name from Alexander Volta, who invented it in 1796. Voltaic cells exist in a great variety of forms, but in all, three parts are invariably present; viz., two conducting plates and a liquid surrounding them. The two plates are called the *elements*, and form together what is generally known as a *voltaic couple.* The liquid is called the *electrolyte.* Briefly then, a voltaic cell consists of a *voltaic pair* or couple and the electrolyte or electrolytes.

The elements of a voltaic couple are most frequently solids; generally, metallic substances. They are sometimes, however, formed of solids and liquids, of solids and gases, or may even be formed of different liquids or different gases.

In a voltaic couple, the elements are generally made in the form of *plates.* During the action of the cell, the metal of one of the plates enters into chemical combination with the electrolyte while the remaining plate is unacted on.

83. One of the simplest forms of voltaic cells is shown in (Fig. 29), where a zinc-copper couple, that is, a couple consisting of a plate of zinc and a plate copper immersed in an electrolyte of dilute sulphuric acid, *i.e.*, water with say two per cent. of sulphuric acid.

If the zinc be chemically pure, no chemical action occurs, provided that the circuit of the voltaic cell is open. As soon, however, as the circuit is closed, as, for

example, by the conducting wire in Fig. 30, a chemical action immediately occurs. The liquid is decomposed, hydrogen gas is given off in bubbles at the surface of the copper plate, and a portion of the zinc plate is dissolved with the formation of a salt of zinc, namely, sulphate of zinc, which dissolves in the electrolyte.

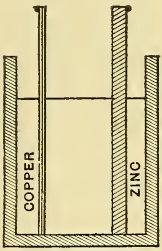


FIG. 29.—SIMPLE FORM OF VOLTAIC CELL ON OPEN CIRCUIT.

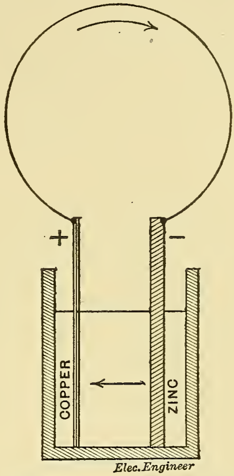


FIG. 30.—SIMPLE FORM OF VOLTAIC CELL ON CLOSED CIRCUIT.

84. These reactions result in the production of a continuous electric current, which flows through the circuit in the direction indicated by the arrows; namely, out from the copper plate through the external circuit, and back to the cell at the zinc plate, completing the circuit by passing through the electrolyte from the zinc to the copper plate. Recalling the convention whereby it is agreed, that the part of a source from which the electric current flows is called the positive

pole, and the part at which it enters, the negative pole, it is clear that the positive pole of the simple voltaic cell shown, will be the terminal of the copper plate, and the negative pole will be the terminal of the zinc plate. Inside the liquid, the direction is reversed, the current passing through the liquid from the zinc plate to the copper plate. For this reason the zinc plate is generally called the *positive plate*, and the copper plate, the *negative plate*. In any voltaic cell it is the positive plate which is dissolved in the electrolyte and the negative plate which is unacted on.

85. That the source of the energy in the voltaic cell is the chemical action of the electrolyte on the plates in the cell, is shown by the fact that as soon as all the active part of the electrolyte is decomposed, or all the positive plate is dissolved, the electrical activity ceases. Moreover, the amount of electrical energy can be readily calculated from the amount of chemical activity.

A voltaic cell in its ordinary form, can never be expected to afford a cheap source of electric energy on a commercial scale, since it requires the consumption of a comparatively costly metal, generally zinc, in dilute acid. It is clear that it must always be cheaper to burn coal in a furnace for energy, than to burn zinc in a battery, since, as is well known, it is necessary to first burn coal, in the reducing furnace, in order to reduce zinc from its ores. In fact, it can be shown with the voltaic battery as it stands to-day, and at the existing prices of coal and zinc, that the cost of electric energy for zinc and electrolyte alone, regardless of labor, can hardly be less

than 28 cents per kilowatt-hour, while the cost of producing electric energy by steam engines, in central stations, for coal alone, is sometimes about one-third of a cent per kilowatt-hour; and including delivery on long lines to consumers, and all charges, it is sometimes 7 cents per kilowatt-hour. Of course, it is possible, in the near future, that some form of voltaic cell may be produced, which when spent or exhausted can be readily re-charged by a simple heating process. Such an invention would, of course, greatly lessen the cost of producing electric energy by the voltaic cell.

86. In the voltaic cell as ordinarily constructed, when the cell is on open circuit no chemical action should take place. In practice, however, where ordinary commercial zinc employed for the positive element is immersed in a strong acid electrolyte, the zinc plate is usually irregularly eaten away, or corroded, although on open circuit.

This irregular corrosion of the zinc is called *local action*. It is due to the presence of minute impurities, generally metals or carbon, which forming small local voltaic couples with the parts of the zinc plate nearest them, cause the solution of the zinc by electrical action around the impurity. In order to avoid local action the zinc plate is usually *amalgamated*, that is, coated with a thin layer of mercury amalgam. The presence of the mercury around the local impurities, destroys the voltaic combinations which previously existed.

88. When in the case of the simple voltaic cell shown in Fig. 29, the circuit is first closed, the electromotive force produced is strongest, and is usually

about one volt. In a very short time, however, this electromotive force diminishes, and, after the current has been flowing for a little while, the E. M. F. may be only half a volt. This diminution of the E. M. F. is due to what is generally called *polarization*, and is produced by the presence of hydrogen, which collects in bubbles on the surface of the copper plate. This hydrogen gas forms a voltaic couple with the copper plate, and the E. M. F. so produced is opposed or acts counter to the original E. M. F. in the cell, and thus diminishes the working E. M. F. This E. M. F. at the copper plate is called the *counter E. M. F. of polarization.*

89. Various plans are adopted in order to avoid the polarization of the negative plate. All practical plans, however, consist in surrounding the negative plate with an electrolyte which will either prevent the hydrogen from being evolved, or will readily combine with it after evolution.

Thus, in the case of the simple voltaic cell of Fig. 30, in order to avoid the polarization of the copper plate from the collection of a film or bubbles of hydrogen on its surface, it might be surrounded by a solution of bluestone, or copper sulphate. Under these circumstances, polarization is avoided and metallic copper is deposited on the copper plate. Or, if the cell shown in Fig. 30 was formed of a voltaic couple of zinc and carbon, instead of zinc and copper, then the formation of the hydrogen on the surface of the carbon plate could be avoided by surrounding the carbon plate with strong nitric or chromic acid, in which case the hydrogen would not be evolved, but would be oxydized, and form water. Such liquids introduced around the negative

plates are termed *depolarizers*. In both of these cases, however, some means would necessarily be required to prevent the depolarizing liquid from attacking the zinc plate, because the depolarizing liquid would be apt to chemically attack the zinc plate, on open circuit. This is generally accomplished by the use of a porous wall or partition separating the two liquids, so that each element is immersed in its own liquid, the electrical current passing through the fine pores in the partition, which are filled with liquid.

90. There thus arise two distinct classes of voltaic cells, namely:

(*1.*) Single-fluid cells.

(*2.*) Double-fluid cells.

No porous partition or cell is employed in any single-fluid cell.

A double-fluid cell cannot be advantageously left on open circuit, even though the zinc be amalgamated. Some of the liquid surrounding the negative plate is sure to pass slowly through the pores of the porous cell, and diffuse or mix through the solution surrounding the positive plate.

Syllabus.

The contact of two conducting surfaces when surrounded by a conducting liquid may result in a continuous flow of electricity.

A voltaic cell consists of a voltaic couple and an electrolyte.

A voltaic couple is generally formed of two dissimilar metallic substances.

In a voltaic cell, during action, the positive plate or

element of the voltaic couple is attacked while the negative plate remains unattacked.

The terminal connected with the positive plate of a voltaic couple is the negative terminal. That connected with the negative plate is the positive terminal.

A voltaic cell derives its activity from the action of the plates on the liquid or liquids in the cell.

Electrical energy costs at least four times more when produced by the voltaic cell than when obtained from a good steam-dynamo machine on a large scale.

To avoid local action, the zinc plate is usually covered with a thin coating of mercury amalgam.

In action, the negative plate tends to become covered with hydrogen gas which causes a polarization of the cell. Polarization is avoided, in practice, by the use of depolarizers.

Voltaic cells may be divided into single-fluid and double-fluid cells.

Laboratory of Houston & Kennelly,
Philadelphia.

WEEKLY.

No. 10. August 18, 1894. Price, - 10 Cents. Subscription, $3.00.

Electrical Engineering Leaflets,

—BY—

Prof. E. J. Houston, Ph. D.
AND
A. E. Kennelly, F. R. A. S.

ELEMENTARY GRADE

The Voltaic Cell.

91. *Single-Fluid Cells.* An early form of single-fluid voltaic cell is found in the Smee cell, which was at one time extensively used, but has long since been replaced, either by better forms of cells, or by the dynamo-electric machine.

The Smee voltaic cell consists of a zinc-silver couple immersed in dilute sulphuric acid, and is shown in Fig. 31. As generally constructed, the silver plate is roughened by a deposit of platinum black, a form of finely divided metallic platinum, which affords numerous points from which the bubbles of hydrogen can readily escape.

92. The Bichromate or Grenêt cell consists of a zinc-carbon couple immersed in a solution of chromic acid in water, or in a solution of bichromate of potash, sulphuric acid, and water.

The bichromate cell has an E. M. F. of about 1.9 volts.

A bichromate cell is shown in Fig. 32. Such a cell, when furnished with a zinc plate 4 in. by 3 in., will

Published by
THE ELECTRICAL ENGINEER,
203 Broadway, New York, N. Y.

[Entered as second-class matter at the New York, N. Y., Post Office, June 14, 1894.]

yield a current of two amperes, with comparatively little polarization. In the form of cell shown, the zinc is intended to be raised out of the electrolyte when the cell is not in use.

93. Various forms of zinc-carbon couples are employed with electrolytes of dilute sulphuric acid, sal-ammoniac, or other salts. The well-known property of carbon to absorb gases in its pores, renders such cells useful for supplying a strong current for a short time

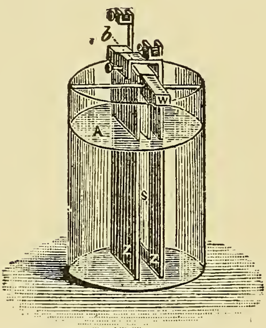


FIG. 31.—ORDINARY FORM OF SMEE CELL.

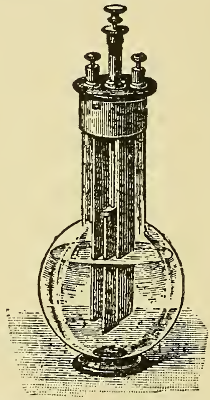


FIG. 32.—GRENET OR BICHROMATE CELL.

without great polarization. For practical use they should be so constructed as to depolarize, provided they are permitted to rest. In order to sustain a strong current, zinc-carbon cells are necessarily made of the double-fluid type.

94. The Daniell cell consists of a zinc-copper couple employing a dilute solution of zinc sulphate around the zinc plate, and a strong solution of copper sulphate

around the copper plate. During action, the copper plate receives an electrolytic deposit of metallic copper, and the solution of zinc sulphate becomes more concentrated by reason of the gradual solution of the zinc plate. This cell is nearly constant in action from the fact that the copper is prevented from polarizing.

95. Fig. 33 shows a form of Daniell cell; the copper plate *c*, is placed inside a porous jar containing a saturated solution of copper sulphate. In order to maintain

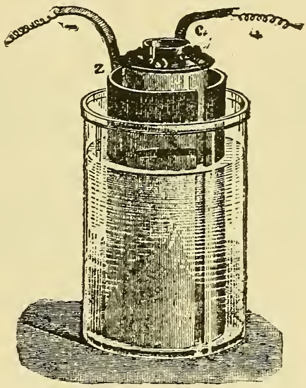


Fig. 33.—Form of Daniell Cell.

the strength of the solution, a perforated cage filled with crystals of bluestone, or copper sulphate, is provided near the top of the jar. As the solution of copper sulphate becomes weakened during use, some of the crystals dissolve, thus keeping the solution saturated. In this form of Daniell cell, the zinc plate is given the shape of a cylinder surrounding the porous jar, and is immersed in zinc sulphate solution.

96. In the Gravity, or Callaud cell, which is a modified form of Daniell cell, the porous partition is dispensed with, and the solutions of zinc sulphate and copper sulphate are kept separated by their differences of density. The zinc sulphate being the lighter solution floats on the surface of the heavier copper sulphate. This variety of Daniell cell is called the gravity cell, on this account. In the cell shown in the figure, the zinc element is cast in the form of a crow's foot, and is supported at the upper part of the glass jar, the copper plate resting at the bottom of the jar. An insulated

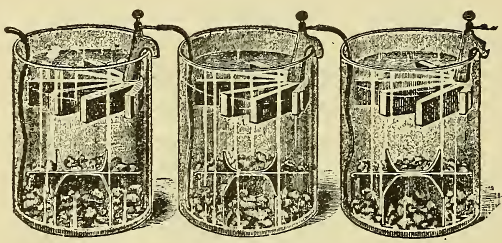


Fig. 34.—Battery of Callaud Cells.

wire extends from the copper plate to the top of the jar. The copper plate is surrounded by a few handfuls of crystals of copper sulphate, and the jar is filled with water; or, in some cases, with water containing a little sulphuric acid. After the cell has been in continued use for a short time, a well marked boundary line can be seen between the denser blue liquid below, and the colorless transparent zinc sulphate above. Fig. 34 shows a battery of three cells of this type connected in series. The gravity cell is best adapted to closed-circuit or continuous current work, since the diffusion which takes

place between the liquids, when the cell is idle, brings on a rapid corrosion of the zinc plates.

The electromotive force of the Daniell cell is about $1\frac{1}{14}$ volts.

97. The Fuller cell consists of a zinc-carbon couple with a heavily amalgamated zinc immersed in dilute sulphuric acid, and the carbon immersed in chromic acid, or electropoion solution. A section of this cell is shown in Fig. 35. This cell is equivalent to the bichromate cell already described, except that the zinc plate is protected

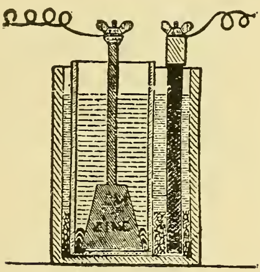


Fig. 35.—Section of Fuller Cell.

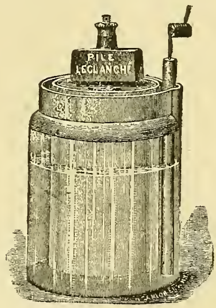


Fig. 36.—Leclanche Cell.

by a porous partition, and does not require to be lifted out of the solution when the cell is not in use.

The electromotive force of the Fuller cell is two volts.

98. *Single-Fluid Cells with Solid Depolarizers.* Between the classes of single and double-fluid cells there is an intermediate class in which, though but a single liquid is used, the negative plate surrounding a solid substance, which acts the part of the second liquid in the double-fluid cell, is employed. To this type belong the following cells: The silver-chloride, the Edison-Lalande, and the Leclanché.

99. In the silver-chloride cell, a zinc-silver couple is employed in a solution of sal-ammoniac in water. The silver element consists of a plate or wire, surrounded by a rod or cylinder of fused chloride of silver, which acts as the depolarizing substance. The electromotive force of the silver-chloride cell is very nearly uniform, when pure materials are employed, and averages $1\frac{3}{100}$ volt.

100. In the Edison-Lalande cell; a zinc-copper couple is immersed in a solution of caustic soda or potash. The copper plate is usually made in the form of an open frame, inside which is a solid block of compressed oxide of copper, forming the depolarizing substance. The electromotive force of the Edison-Lalande cell averages $\frac{2}{3}$ volt, when at work; and, as the resistance is very low, the cell is suitable for driving small motors and lighting small lamps.

101. In the Leclanché cell, shown in Fig. 36, a zinc-carbon couple is employed, immersed in a solution of sal-ammoniac. The carbon is surrounded by a mixture of black oxide of manganese and powdered carbon. The black oxide of manganese forms the depolarizing substance. The Leclanché cell has an E. M. F. of nearly $1\frac{1}{2}$ volts. It is only suitable for open-circuit or intermittent work, and is employed largely for bells and signalling; since, although provided with a depolarizer, it requires rest in order to depolarize.

102. In order to obtain powerful currents, voltaic cells require to be suitably connected. Where the circuit supplied has a low resistance the cells should

be connected in parallel; where the circuit supplied has a high resistance the cells should be connected in series.

103. Fig. 37 shows a variety of the so-called dry battery, that is, a battery without a liquid electrolyte. In reality the term dry cell is a misnomer, since, as already stated, all voltaic cells consist essentially of a voltaic couple and an electrolyte. The so-called dry cell has the exciting liquid held in suspension by an absorbent substance, such as sawdust or gelatine. The E. M. F. of dry cells does not differ appreciably from that of ordinary cells

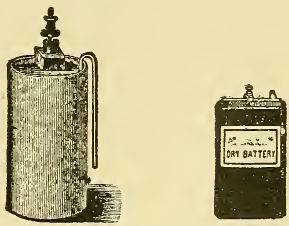


FIG. 37.—DRY CELLS.

employing the same elements and the same electrolyte in fluid form, but their internal resistance is much higher.

104. Since, in the case of any simple voltaic cell, the E. M. F. is the result of the contact of the metals with the electrolyte, the value of the E. M. F. so produced, is independent of the size of the elements in contact; in other words, no increase in E. M. F. is obtained by increasing the size of a voltaic cell. A cell no larger than a thimble would have the same E. M. F. as one the size of a hogshead, provided, of course, that the same materials were employed in each.

There would, however, necessarily be this difference, that the ability of the larger cell to supply current would

be enormously greater than that of the smaller cell, not only on account of the greater amount of material present in the electrolyte and elements, but also because the greater area of immersed surfaces in the larger cell enables a much larger total current to be supplied at any moment without polarizing. The larger cell would, therefore, have a capacity in coulombs or in ampere-hours far in excess of that of the smaller cell.

Moreover, since the area of cross-section of the immersed plates is so much greater, the internal resistance of the cell would be proportionally less; and, since the E. M. F. is the same, the current supplied would, in accordance with Ohm's law, be greater.

Syllabus.

Voltaic cells may be divided into three classes:

(*1.*) Single-fluid cells. (*2.*) Single-fluid cells with solid depolarizer. (*3.*) Double-fluid cells.

The principal form of single-fluid cell in actual use consists in a zinc-carbon couple immersed in chromic acid.

The principal single-fluid cells with solid depolarizers are: The Silver-Chloride, the Edison-Lalande, and the Leclanché.

The principal double-fluid cells are the Daniell and the Fuller.

When the external circuit of a voltaic battery has a high resistance, the separate cells forming such battery are usually connected in series. When the external circuit has a low resistance, they are usually connected in parallel.

Laboratory of Houston & Kennelly,
Philadelphia.

WEEKLY.

No. 11. AUGUST 25, 1894. Price, - 10 Cents. Subscription, $3.00.

Electrical Engineering Leaflets,

—BY—

Prof. E. J. Houston, Ph. D.

AND

A. E. Kennelly, F. R. A. S.

ELEMENTARY GRADE.

THE VOLTAIC CELL.

105. Of the different cells that we have described, certain types are best adapted for particular characters of work. Where a battery is only called on to provide current for a few moments at a time, at comparatively long intervals, cells of the Leclanché type, in which carbon is employed as the negative plate, are probably the best. These cells give a high E. M. F. and, although they polarize readily, if kept at work, yet, if sufficient intervals of rest are afforded, they will furnish comparatively strong currents, with very little attention. It is not unusual for batteries of such cells to continue in efficient working order, upon such discontinuous work as bell ringing, for a year or more without attention.

For closed-circuit work, that is, for all cases in which continuous currents of, say, less than one-half ampere, have to be provided, the Callaud or gravity cell, is most suited. These cells are cheap, economical in materials

Published by
THE ELECTRICAL ENGINEER,
203 Broadway, New York N. Y.

[Entered as second-class matter at the New York, N. Y., Post Office, June 14 1894.]

consumed, and require comparatively little attention to maintain. Moreover, the copper deposited on the negative plate, during the action of the cell, is of commercial value.

Where a steady current of over one-half ampere is required, some form of carbon-zinc bichromate cell is suitable. Large cells of this type are capable of supplying five amperes steadily. Being of the double-fluid type, however, there is necessarily considerable loss by diffusion of the liquids, unless the cell is worked continuously. These cells are, therefore, unsuited to intermittent work.

For steady currents up to five amperes or more, through a circuit of low resistance, the Edison-Lalande cell possesses marked advantages. Its internal resistance being extremely low, and its working E. M. F. being about $\frac{2}{3}$ volt, the current it can supply through a circuit of low resistance is considerable. Moreover, it can continue to furnish this current, with very little departure from the normal, until completely exhausted, provided, of course, the current is not carried above the limit for which the cell is intended; and, since this cell belongs to the type of single-fluid cells with solid depolarizers, no loss by diffusion is possible.

106. With voltaic cells as they exist to-day it is impossible economically to produce electrical energy at a rate that can compete with its production from dynamo-electric machines. As we have already seen, the source of energy in the voltaic cell is to be traced to the actual burning or consumption of metallic zinc in the electrolyte. Not only does zinc cost about $156.80 a ton, against coal at, say, about $3.00 a ton,

but the energy which is liberated in the consumption of a ton of zinc is only about $\frac{1}{6}$th of the energy liberated in the consumption of a ton of coal. Although it is true that good engines can only utilize about $\frac{1}{10}$th of the energy liberated during the consumption of the coal, yet, even on this basis, zinc would have to be provided, at about $5 per ton, in order to compete equally with coal for producing electrical energy. In this estimate the cost of the electrolyte is considered as offset by the cost of the boilers, engines, and dynamos.

It has been calculated that a kilowatt-hour, when produced by the best voltaic batteries, costs $0.28 independently of labor, while a kilowatt-hour can be produced in a large central station by steam dynamos for say $0.05, and the same amount of energy, after delivery over comparatively long lines to consumers, may cost $0.07.

It is not impossible, that, in the near future, some form of voltaic cell may be devised in which electrical energy is directly produced by the consumption or burning of carbon. Theoretically such a cell would have a very high electromotive force, and, since the price of coke is low, the cost of a kilowatt-hour so produced might be greatly less than that produced by the dynamo.

107. Of the great variety of voltaic cells that have been devised and tried, only a few have survived in the struggle for existence, as is evident from their extensive commercial use to-day. With the exception of the Smee, these cells are those described above. Of these, two markedly possess the required properties; viz., the Leclanché cell for open circuit work, and the gravity cell for closed-circuit work. The reason for their extended

use is principally economy; that is to say, these cells satisfy the requirements at a lower cost than the others.

108. Since the Daniell and Leclanché cells are quite extensively used, the following particulars concerning their practical operation may be of value.

In the use of the Leclanché cell, care should be taken not to fill the jar with the exciting solution more than two-thirds full. Since when filled much beyond this limit, a defect of the cell, termed *creeping*, is apt to cause trouble. Creeping is a term employed to describe the crystallization of the sal-ammoniac in the exciting solution on the walls of the cell above the surface of the liquid. It is due to the crystallization of the salt upon the sides of the cell on the evaporation of the liquid. Creeping is objectionable, both because it weakens the solution, and because it may short-circuit the cell. It may be avoided by dipping the top of the cell into melted paraffin wax. Or, the surface of the liquid may be covered with a coating of oil, which moreover, possesses the general advantage of checking the evaporation from the cell and, thereby, avoiding too concentrated a solution. The best method, however, in the case of the Leclanché cell, for avoiding both creeping and evaporation, is to hermetically seal the cell.

Care should be taken in the use of the Daniell cell not to permit the zinc sulphate solution to become too strong. This can be avoided by withdrawing some of the liquid from the jar at suitable intervals and replacing it by fresh water. Moreover, in order to maintain a concentrated solution of copper sulphate, a sufficient amount of the undissolved crystals of the salt should be kept in the cell. Creeping and evaporation of the liquid

in this cell, can be avoided by the use of a coating of paraffin wax around the rim, and a layer of oil above the solution. The cell cannot, however, be conveniently sealed. This cell should be located in a dry place, under circumstances where it can be readily inspected. It is a mistake to set batteries in dark closets where their condition cannot readily be examined.

109. The Gravity-Daniell has very generally displaced the original form of Daniell with porous cell or partition, since, not only is the expense and additional resistance of the porous cell avoided, but also the deposit of copper which will form upon the porous cell is avoided.

It is a mistake to suppose that the glass jar of a cell affords sufficient insulation against all loss of current by leakage in a large battery of many cells. The tendency of moisture from the air to collect on the outside walls together with the layer of dust that forms on the cell, renders leakage from these causes very appreciable when the total E. M. F. is high. The insulation necessary to avoid serious loss from leakage, may be conveniently obtained by resting the legs of the tray or support on suitable insulators.

110. When the conditions of the consumption circuit are such that the internal resistance of the cell is too great to permit the entire battery to be connected in series, it is preferable to employ larger cells of the necessary size, rather than to connect a number of similar cells in multiple-series. The reasons for this are, not only because the larger cell is relatively cheaper than a number of smaller cells of the same equivalent resis-

tance, but also because, should one cell or series of cells become exhausted sooner than another, or any accident occur to reduce its E. M. F., the neighboring series may discharge through the weaker group to the detriment of the battery. When it is necessary to connect any of the cells of the battery in multiple-series, additional inspection is required on this account.

111. When a bluestone or gravity cell is first set up, the internal resistance of the cell is so high that the current strength it furnishes remains small for some time. It is usual to short-circuit the battery for about 24 hours, so as to form zinc sulphate and reduce the internal resistance of the cell. When, however, the full current strength is desired immediately, this can be obtained by adding a small quantity of sulphuric acid to the solution. The effect of the acid is to decrease the internal resistance of the cell.

112. Care should be taken that the brass connectors or binding posts are clean, and free from films of oxide, as it is not uncommon for considerable undue resistance to be introduced in this manner to the detriment of the battery's action.

113. Various forms of binding posts or connectors in common use are shown in Fig. 38.

Here three types are shown, namely: Those which connect wires with wires on a fixed support; those which connect unsupported wires; and those which connect straps or plates, *i. e.*, flat conductors. Nos. 1 to 6 of Fig. 38 belong to the first type; No. 7 belongs to the second type, and No. 8 to the third.

The connection by means of a binding post is a con-

venient substitute for a soldered joint, and is only justified, either by the pressure of a temporary necessity, or by the necessity which frequently exists for readily opening or closing the circuit at such joint. Whenever, therefore, this method of jointing is adopted, care should be taken to avoid the introduction of unnecessary resistance. The wires should therefore be scraped and cleaned

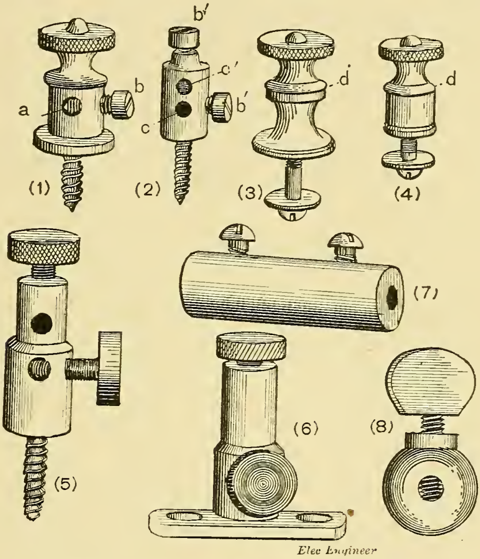


Fig. 38.—Various Forms of Binding Posts.

before being connected. The pressure which is brought to bear upon the wires by the action of the screw, is designed to bring as much of the surface of the wires into intimate contact as possible; consequently where the binding post has a hole through it, as at *a* in (1), the nearer the size of the wire is to that of the hole, the better. Care should be taken to protect the binding

post and its wires, from moisture, since the capillary spaces left round the wires may cause the moisture to enter and oxydize the metallic contact.

Nos. (1), (3) and (4) are intended for at least one loop connection, *i. e.*, one wire at least has its end bent in the form of a loop and clamped between the shank and thumbscrew. The loop should always be laid on the shank, right-handed, so as to be closed and not to be opened by the clamping of the screw. No. (7) should either be employed in an emergency or for temporary purposes, as for example, during an experiment. In all other cases a properly soldered joint should be employed. No. (8) is a screw clamp frequently used to connect battery straps.

Syllabus.

The Leclanché cell is specially fitted for open-circuited work; the gravity cell for closed-circuited work.

Voltaic batteries as at present constructed can never compete with dynamo-electric machines in the production of large currents.

Creeping, or the deposit of a layer of crystals on the cell above the level of the exciting liquid, can be avoided by covering the liquid with a thin layer of suitable oil.

In order to avoid loss of current by leakage, the cells of a voltaic battery should be supported on suitable insulators.

Laboratory of Houston & Kennelly,
Philadelphia.

WEEKLY.

No. 12. SEPTEMBER 1, 1894. Price, - 10 Cents. Subscription, $3.00.

Electrical Engineering Leaflets,

—BY—

Prof. E. J. Houston, Ph. D.
AND
A. E. Kennelly, F. R. A. S.

ELEMENTARY GRADE.

Magnetomotive Force

---

114. A magnetized needle, such as ordinarily employed in pocket compasses; if brought anywhere in the neighborhood of a dynamo-electric machine in operation, will be violently agitated, vibrating rapidly, but pointing generally towards one of the poles of the machine. These oscillations are more marked the nearer the needle is brought to the machine, decreasing as it is carried from the machine, and becoming imperceptible when carried far enough away. The oscillations are more marked in certain directions, but may be detected in any part of the surrounding space. These oscillations of the needle are due to the action of a *magnetic field*; that is, to the magnetism pervading the region or space surrounding the dynamo.

The presence of a magnetic field may be shown by other means than by the magnetic needle. For example, if a glass plate or a sheet of paper, stretched tightly across a wooden frame, be brought into any portion of

Published by
THE ELECTRICAL ENGINEER,
203 Broadway, New York N. Y.

[Entered as second-class matter at the New York, N. Y., Post Office, June 14 1894.]

the space in which the magnetic needle showed violent oscillations, and the plate or sheet be dusted over with fine iron filings, it will be found that these filings take up definite positions of rest, if aided in doing so by lightly tapping the plate or frame. Moreover, practically the same figure will invariably be repeated if the plate or sheet be repeatedly exposed at the same position to the same treatment.

115. Fig. 39 shows a delineation of the magnetic field of a bar-magnet mapped out in this way. Here it will be observed that the particles of iron are

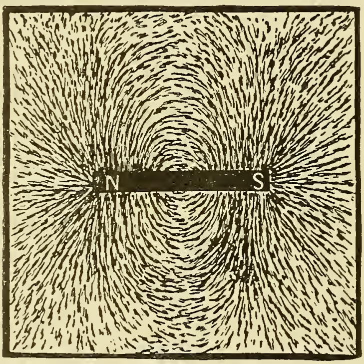


FIG. 39.—MAGNETIC FIELD OF A BAR MAGNET AS MAPPED OUT BY IRON FILINGS ON A PLATE PLACED FLAT UPON MAGNET.

arranged in separate and apparently independent chains, which mark the paths of streamings existing in the space around the magnet. These stream-lines of iron filings are believed to be occupied by lines of magnetic force, which are more properly called lines of magnetic flux, or magnetic flux-paths.

As in the case of the electric current, electricity is assumed to leave an electric source at its positive pole, and

after passing through the circuit to re-enter the source at its negative pole; so in the case of a magnet, the magnetism, or magnetic flux, is assumed to leave the magnet at its positive pole, and, after passing through the space surrounding the magnet, to re-enter it at its negative pole. All magnetic flux-paths, therefore, form closed circuits, as is shown in many of the lines of Fig. 39. All these lines would show closed circuits, were the limits of the figure not circumscribed.

116. The positive pole of a magnet is the name given to its north, *i.e.*, its north-seeking pole; that is, to the pole which, if the magnet were freely suspended, would point approximately to the geographical north. The negative pole is the south-seeking pole, and is usually called the south pole.

In any magnetic field, a freely suspended magnetic needle assumes the direction of the magnetic flux at the point it occupies. In the magnetic field, as mapped out by iron filings, each particle of iron becomes a minute magnet and assumes the direction of the magnetic flux, so that chains of magnetized fillings correspond to flux-paths.

In Fig. 40, the magnetic flux is represented by curved lines, which are assumed to leave the magnet at its positive, or north pole, and to re-enter it at its negative, or south pole, passing through the magnet and again completing the magnetic circuit by taking a path of the dotted lines as shown.

The small magnetic needles show the direction of the flux from point to point, the north-seeking pole at any point taking the direction of the flux at that point.

117. An electric source can not properly be regarded as producing electricity. What it really produces is an electromotive force, and this electromotive force, if permitted to act, produces an electric flux or current in its circuit.

Similarly a magnetic source, *i. e.*, a magnet, can not be regarded as producing magnetism, but rather as producing a *magnetomotive force* which in its turn produces magnetic flux in its circuit.

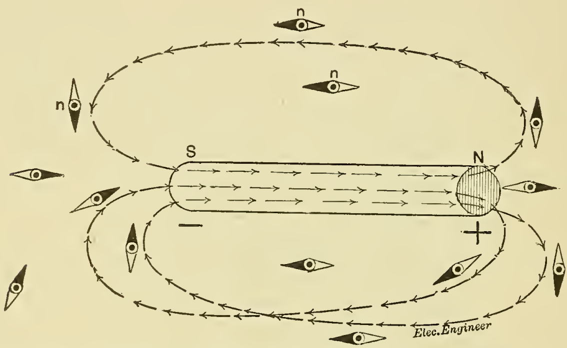


FIG. 40.—CYLINDRICAL BAR MAGNET WITH DIAGRAMMATIC TRACING OF THREE SEPARATE FLUX-PATHS THROUGH THEIR ENTIRE CIRCUIT.

118. In Fig. 39 we have shown the magnetic flux as being limited to the positions of space, roughly covered by the stream lines. In point of fact, such a figure does not correctly represent the condition of things which we must believe exists in the neighborhood of every magnet, no matter what its shape. For not only the space indicated in the figure by the stream lines, and not only the space between the stream lines, but also the space extending for a long distance beyond is permeated by magnetic flux. While the exact nature of magnetism is

far from being understood, yet the effects are the same as if fluid streams were continually being forced through the magnet so as to issue at its north pole, and re-enter it at its south pole, passing in its circulation through all surrounding space. Magnetic flux, therefore, differs from electric flux in this respect, that we can, for our present purposes, regard the electric flux as being limited to the substance of the conductor through which it is passing, and not as existing in the space outside the conductor; while in the magnetic circuit the magnetic flux is not confined to any particular stream path; or, in other words, insulators exist for electric flux, but not for magnetic flux.

119. In a magnetic source, the force that sets up magnetic flux is called the *magnetomotive force*, generally contracted, M. M. F. In all cases, therefore, where magnetic flux exists, we must assume the existence of a magnetomotive force producing it.

Magnetomotive force may be produced in two ways, viz.:

(*1.*) By matter. That is, associated with permanent magnetism, which is an inherent property of the ultimate particles of certain magnetic metals, such as iron, nickel, cobalt, etc.

(*2.*) By the action of an electric current. All conductors conveying an electric current being, as we have seen, magnetized, *i. e.*, surrounded by magnetic flux.

A permanent magnet, which is usually a bar of hardened steel, differs from a bar of soft iron, in that it retains its magnetism, *i. e.*, acts as a permanent source of M. M. F.; while an electric conductor, carrying a current, acts only as a temporary source.

In nearly all working magnetic circuits, soft iron forms a considerable portion of the path of the magnetic flux, because the resistance, which soft iron offers to such passage, may be regarded as being very small, compared with that of air.

120. Fig. 41 represents a common type of dynamo, in which there is a single magnetic circuit. Here the path, through the field magnets and the armature core

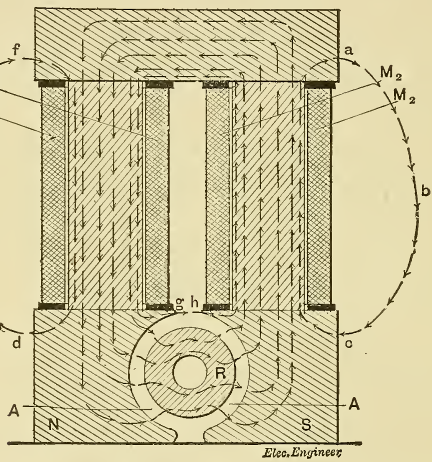


Fig. 41.—Section of a Common Type of Dynamo with Magnetic Circuit Indicated.

R, passes through iron, except in the air gaps A A, between the revolving armature and the surrounding pole faces. The M. M. F. which produces this magnetic flux is due to the action of the electric current which passes through the coils of wire M_1 M_1 and M_2 M_2, the flux-paths being as indicated by the dotted arrows. Some of these flux-paths, such as *a b c* and *d e f*, do not pass

through the armature at all, and are therefore called *leakage flux-paths.*

The M. M. F., driving the flux through the circuit, depends on the current strength passing through each turn of wire forming the coils, and, as the turns are all in series, and the current strength is the same in each, the M. M. F. is also proportional to the number of turns. The M. M. F. is, therefore, proportional to the number of amperes passing through the field magnet coils, multiplied by the number of turns in those coils. From this point of view, therefore, the number of *ampere-turns* on the field magnets determine the M. M. F., driving the flux through the circuit.

121. The unit of M. M. F. is called the gilbert, from Dr. Gilbert, an early authority on magnetism (1600 A. D.). A gilbert represents such a M. M. F. as would be produced by about $\frac{4}{5}$ ampere turn. In order, therefore, to determine the M. M. F. in gilberts produced in any magnetic circuit, by a given current strength, it is only necessary to multiply that current strength, expressed in amperes, by the number of turns through which it circulates, and to multiply the product by $1\frac{1}{4}$.

122. In an electric circuit electromotive forces may aid or oppose one other; that is, must be added or subtracted in order to obtain their total resultant. So in a magnetic circuit M. M. F.'s may aid or oppose each other, according as they act in the same or in opposite directions.

Syllabus.

The neighborhood or space surrounding a dynamo in action is pervaded by magnetic flux, as may be shown by the action of suspended magnetic needles brought into such space.

Magnetic flux is more powerful near a dynamo than at a distance from it. The existence of a magnetic field or region may be shown by sprinkling iron filings on a flat surface brought into a magnetic field.

Magnetic flux is assumed to leave a magnet at its positive or north-seeking pole and to re-enter it at its negative or south-seeking pole, completing the magnetic circuit by passing through the substance of the magnet.

The force producing a magnetic flux in a magnetic circuit is called M. M. F., just as the force producing an electric flux in an electric circuit is called E. M. F.

The unit of magnetomotive force is called the gilbert, and is approximately equal to the M. M. F. produced by $\frac{4}{5}$ ampere-turn.

Laboratory of Houston & Kennelly,
Philadelphia.

WEEKLY.

No. 13. SEPTEMBER 8, 1894. Price, - 10 Cents. Subscription, $3.00.

Electrical Engineering Leaflets,

—BY—

Prof. E. J. Houston, Ph. D.
AND
A. E. Kennelly, F. R. A. S.

ELEMENTARY GRADE.

Magnetic Reluctance.

123. As we have already seen, in an electric circuit, the electric flux or current produced by a given E. M. F. depends on the resistance of the circuit. In the same manner in a magnetic circuit, the magnetic flux produced by a given M. M. F. depends on the magnetic resistance of the circuit, or, as it is usually termed, on the *reluctance* of the circuit. By the reluctance of a medium is meant the resistance which such medium offers to the passage through it of magnetic flux under a given M. M. F. Unlike resistance in the electric circuit, the reluctance of nearly all substances, with the exception of iron and the other magnetic metals, is practically the same, so that whether a magnetic circuit be made of wood, air, or copper, the flux through it under a fixed M. M. F. is practically the same.

124. A marked difference exists between the electric and the magnetic fluxes, as regards the exact paths they take in a circuit. In the case of the electric cir-

Published by
THE ELECTRICAL ENGINEER,
203 Broadway, New York N. Y.

[Entered as second-class matter at the New York, N. Y., Post Office, June 14, 1894.]

cuit, this path is usually fixed and definite. For example, in Fig. 42, if a voltaic cell is connected in the conducting circuit A, B, C, the electric flux or current is confined to the conductor, flowing as indicated by the arrow, and there is no current outside the wire. On the contrary, in the case of Fig. 43, which represents the magnetic flux produced by the M. M. F. of a single turn, carrying a current, the magnetic flux, in its circuit through the air, is not confined to any particular line or region, but

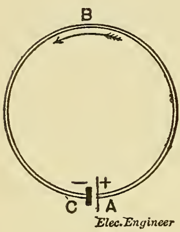


FIG. 42.

Diagram of electric circuit with a current produced by an E. M. F. strictly confined to the conducting wire.

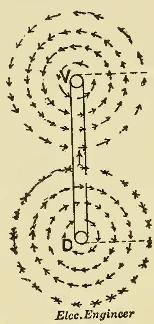


FIG. 43.

Section of a circular loop diagram of a magnetic circuit with a flux produced by a M. M. F. from a single turn of active conductor, and showin the flux distributed through the air.

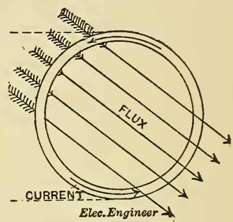


FIG. 44.

Diagram indicating the direction of the flux as dependent on the direction of the current in the loop of wire producing M. M. F.

spreads through all the surrounding space, being densest in the immediate neighborhood of the wire, and feebler the further we depart from the loop. The arrows along the circular paths show only approximately the distribution of the flux, the actual system of flux-paths being more complex. The true distribution is known, and can be mapped out by the aid of a small compass needle, as already explained.

Fig. 44 indicates the direction of the flux through a loop as dependent upon the direction of current round the loop. The flux is represented as flowing through the plane of the paper towards the observer. On reversing the current round the loop, the flux would reverse or pass down through the paper.

125. The reason for the diffusion of the magnetic flux here shown, is that there is no known magnetic insulator, while, as is well known, in the case of an electric circuit, the air surrounding the wire A, B, C, acts as a perfect insulator, and confines the current entirely to the wire.

Any coil of wire, or any magnet, may, therefore, be regarded as a magnetic source, capable of producing a magnetic flux through the medium surrounding it, generally the air.

126. Although the exact dimensions of a magnetic circuit are usually indefinite, in the sense of being indefinitely extended, yet the amount of reluctance, which any given path offers to the passage of the flux, is definite, and increases directly with the length of such path. That is, if the length of any flux-path be doubled, while retaining the same cross-section, its reluctance will be doubled; and similarly, if the length of the path be halved, with the same cross-section, its reluctance will be halved. The law of magnetic reluctance in this respect is identical with the law of electric resistance.

127. When a wooden ring is wrapped with a coil of wire, which carries a steady current supplied through the leads l_1 l_2, as shown in Fig. 45 *a*, the magnetic flux due to the M. M. F. produced by the current, is con-

fined to the space within the substance of the ring, no flux existing outside the ring, as is shown by the absence of any magnetic action on iron filings or a compass needle outside the coil.

The reluctance of the circuit in this case is directly proportional to the mean length of the circuit or circle A, B, C, and diminishes, as the area of cross-section of the ring increases. If we double the length of the ring as shown in Fig. 45 *b*, retaining the same cross-section in the wood, we double the reluctance of the circuit; or, if we

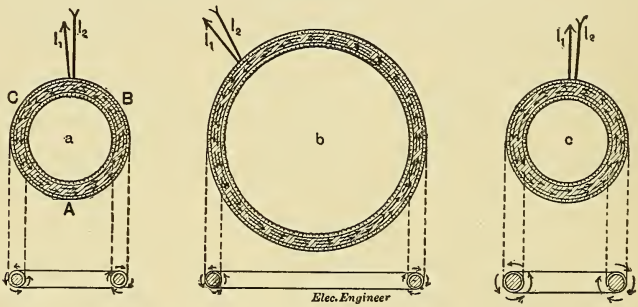


Fig. 45.

Plans and sections of three wooden rings uniformly wrapped or wound with insulated wire carrying a steady electric current. The M. M. F. produced by the current-turns round the ring, produces in each case a magnetic flux through the wooden substance of the ring in circular paths as indicated by the arrows.

double the cross-section of the ring, with the original length, as shown in Fig. 45 *c*, the reluctance of the circuit is halved.

128. Here it will be noticed that the laws governing the reluctance of a magnetic circuit are identical with those governing the resistance of a wire forming an electric circuit. The reason is to be found in the fact that this form of coil is the only form in which a magnetic circuit undergoes no diffusion, being confined to the interior

of the coil or ring. For all other forms, *i. e.*, where magnetic diffusion or leakage occurs, the reluctance of the circuit suffers corresponding modifications. Even in the case of Fig. 45, if the winding be only applied to half the ring, the effect will be to produce a flux distribution outside as represented in Fig. 46, and in this case the reluctance of the circuit is much less than in that of Fig. 45 *a*.

Or if, as in Fig. 47, the direction of the winding be

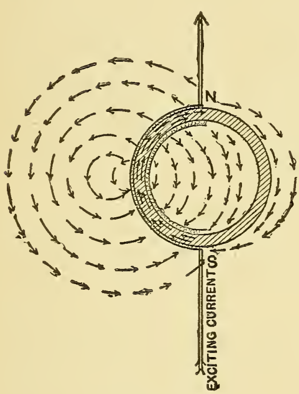


Fig. 46.

Diagram of magnetic circuit of wooden ring half wound with active wire.

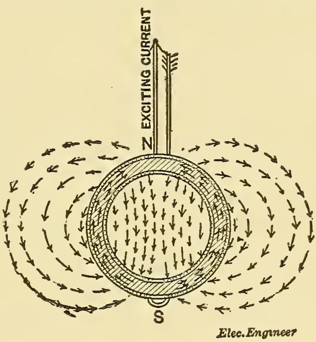


Fig. 47.

Diagram of magnetic circuit of wooden ring completely wound with active wire, but with direction of winding reversed at s.

reversed at the point s, two equal and opposite m. m. f.'s are produced, causing the separate fluxes in separate circuits, as shown, and the ring is said to exhibit north and south polarity at n and s, respectively, in which case also, owing to the more complex form of the circuit, its reluctance is more difficult to estimate.

The flux-paths will in these cases diffuse as generally

indicated by the figures, and the reluctance of the circuit will differ materially from the previous case. Still the general law holds good, even in the most complex cases; the longer the circuit, and the narrower its cross-section, the greater the reluctance.

129. If the ring core of wood, represented in Fig. 45, be replaced by a ring of soft iron, we obtain an iron or ferric magnetic circuit. The difference between this and the non-ferric, *i. e.*, wood, copper, or air circuit, lies in the fact that the magnetic resistance or reluctance of the iron being far less, the magnetic flux traversing the circuit becomes far greater. If, in the above case, a suitable variety of soft iron were used instead of wood, the reluctance of the ferric circuit may readily be 1,000 times less, and, therefore, the magnetic flux through the substance of the ring, 1,000 times greater.

A soft iron, ring core, wrapped as in the figure, has little or no external magnetism; *i. e.*, has no polarity which can be detected by a compass needle.

Although such a ring possesses no external magnetism, yet in point of fact it is powerfully magnetized within its substance; *i. e.*, is traversed by a powerful magnetic flux, which may be rendered evident by a saw-cut passing through the ring at any place, when the walls of the cut develop powerful opposite polarities.

130. Most useful magnetic circuits are compound, or aero-ferric in type; that is, part of the magnetic circuit lies through iron, and the remainder through air or copper. For example, if the ring, previously considered, be rendered discontinuous as shown in Fig. 48, and wrapped with wire, then a powerful flux passes

through the iron circuit as before and is continued through the air-gap between the poles N and S.

Since the reluctance of iron is usually very small, almost the entire reluctance of an aero-ferric circuit lies in the air. Therefore, when it is desired to reduce the reluctance of the circuit, the air-gap is made of as large an area of cross-section, and of as small a length, as possible.

131. A very common modification given to the form of aero-ferric circuit shown in the last figure is seen in Fig. 41, where there are two air-gaps in series.

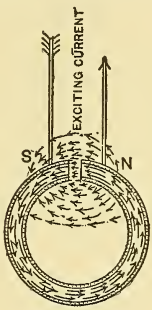


FIG. 48.

Diagram of magnetic circuit of iron ring with air-gap (aero-ferric circuit).

Here we must consider that two separate M. M. F.'s exist, one on each core and produced by the current circulating in the magnetizing or field coils.

132. The unit of reluctance is called the *oersted*, from Hans Christian Oersted, who, in 1820, discovered the magnetic effects of an electric current.

If we could isolate a little cube of air space, the edges of the cube having a length of one centimetre, (approximately $\frac{4}{10}$ths inch) the reluctance of this prism or cubical column of air, measured between any pair of opposite faces, would be one oersted.

133. The reluctance of air is the same at all flux densities, just as the resistance of a copper wire is independent of the current strength through it, assuming its temperature to remain the same. This is far from being the case, however, with iron or steel. Here the reluctance increases rapidly with the flux density, and, when the iron is so powerfully magnetized as to be *saturated*, its reluctance becomes practically as great as that of air, but at no flux density can the reluctance of the iron exceed that of a similar volume of air.

SYLLABUS.

The reluctance of a medium is the resistance that medium offers to the passage of a magnetic flux through it.

An electric flux can be directed through a conducting path by the aid of suitable insulators. As no known insulator exists for the magnetic flux, its circuit cannot, therefore, be sharply limited.

The reluctance of a given magnetic circuit increases with the length of the circuit and diminishes with its area of cross-section. Magnetic circuits may be divided into three classes:

(*1.*) The non-ferric, in which the entire path of the circuit traverses air or other non-magnetic material.

(*2.*) Ferric circuits, in which the entire path traverses iron or other magnetic materials.

(*3.*) The aero-ferric circuit, in which the circuit is partly completed through air and partly through magnetic materials.

The unit of magnetic reluctance is called the oersted and is the reluctance of a cubic centimetre of air.

Laboratory of Houston & Kennelly,
Philadelphia.

WEEKLY.

No. 14. SEPTEMBER 15, 1894. Price, - 10 Cents. Subscription, $3.00.

Electrical Engineering Leaflets,

—BY—

Prof. E. J. Houston, Ph. D.
AND
A. E. Kennelly, F. R. A. S.

ELEMENTARY GRADE.

MAGNETIC FLUX.

134. In accordance with Ohm's law, the electric flux in any circuit is equal to the electromotive force acting on the circuit, divided by the resistance of the circuit. The magnetic flux in any magnetic circuit is equal to the M. M. F. acting on the circuit, divided by the reluctance of the circuit. The expression for the electric circuit is,

$$\text{the amperes} = \frac{\text{volts}}{\text{ohms}};$$

that is, the current strength in a circuit is equal to the quotient of the volts by the ohms; this corresponds with the expression for magnetic circuit,

$$\text{the webers} = \frac{\text{gilberts}}{\text{oersteds}};$$

that is, the strength of the magnetic flux in a circuit is equal to the quotient of the gilberts divided by the oersteds.

Moreover in an electric circuit, the amperes multiplied

Published by
THE ELECTRICAL ENGINEER,
203 Broadway, New York N. Y.

[Entered as second-class matter at the New York, N. Y., Post Office, June 14, 1894.]

by the ohms equals the volts; so, in a magnetic circuit, the webers multiplied by the oersteds equals the gilberts. Again, as in the electric circuit,

$$\text{the ohms} = \frac{\text{volts}}{\text{amperes}},$$

so in the magnetic circuit,

$$\text{the oersteds} = \frac{\text{gilberts}}{\text{webers}};$$

or, generally, any two of the three quantities being known in either circuit, the other may be calculated.

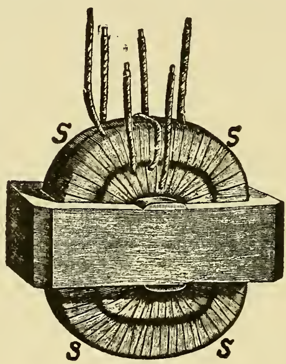


FIG. 49.
Ferric Magnetic Circuit. Alternating Current Transformer.

135. Magnetic flux, however produced, invariably flows in closed circuits. As already stated, magnet circuits are of three kinds; viz.; ferric, non-ferric, and æro-ferric.

A ferric circuit is shown in Fig. 49, which represents an alternating current transformer. In such a transformer the object is to send a powerful magnetic flux through the outer coil of wire, s s s s, This flux is produced by the M. M. F. of the inner coil, which is traversed

by an electric current. The arrangement is equivalent to that represented in Fig. 50, where a ferric magnetic circuit carrying a magnetic flux under the influence of a M. M. F., M, is linked with a second electric circuit S. The shaded portions A B C, represent plates of soft iron through which the flux circulates, as indicated by the arrows. At every alternation of the current in the transformer, this flux is reversed in direction, as will be shown in a subsequent leaflet. The branching of the magnetic circuit is similar to the case shown in Fig. 51, where an E. M. F., namely, a voltaic battery, is provided with a double or bi-

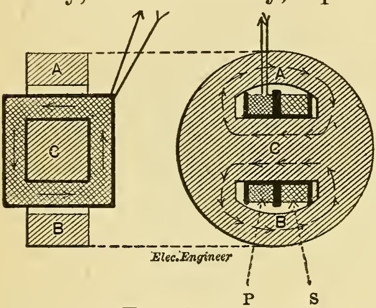


FIG. 50.
Ferric Magnetic Circuit. Flux established by M. M. F. in coil P.

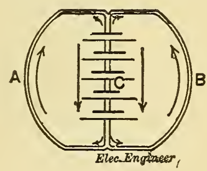


FIG. 51.
Equivalent Electric Circuit.

furcated circuit, A and B. Since this is entirely a ferric circuit, its reluctance is very low, and, consequently, the magnetic flux produced by a given M. M. F. is great.

136. An æro-ferric circuit is seen in Fig. 52. Here, as in all æro-ferric circuits, the reluctance is partly due to air in the space between poles and armature, and partly due to iron in the rest of the circuit.

In small dynamos, or ordinary electromagnets which attract their keepers over an appreciable width of air-gaps, the principal reluctance in the magnetic circuit lies

in the air-gaps. In large dynamos, however, it may happen that the reluctance in the air is less than the reluctance in the iron portions of their circuits. It is, therefore, desirable, in order to obtain a powerful magnetic flux, that the air-gaps in the magnetic circuit of an ordinary electromagnet should be as short as possible, and the area of polar surface at the gaps as large as possible.

137. In all practical magnetic circuits, the flux produced is designed to traverse some device placed in its path. Thus, in the case of a dynamo, the flux is

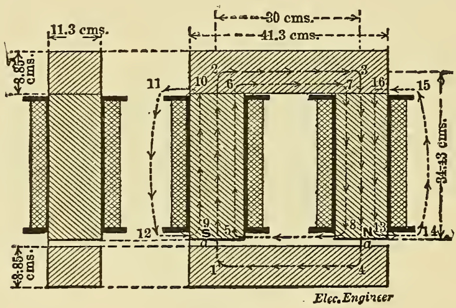


Fig. 52.

Electromagnet of wrought iron æro-ferric circuit. Air gaps ½ in. = 1.27 cm. Mean length of magnetic circuit 140.24 cms. Cross-section of magnetic circuit 25 sq. cms.

designed to pass through the armature. In the case of an electromagnet, through its keeper, and, in alternating current transformers, through the secondary coil. Any flux which fails to pass through the proper device is called *leakage flux* or *magnetic leakage*. Thus, in Fig. 52, four separate magnetic circuits are diagrammatically indicated by the paths of arrows 1, 2, 3, 4; 5, 6, 7, 8; 9, 10, 11, 12; and 13, 14, 15. 16. Of these only the first is the main circuit passing through the keeper, and available

for exerting tractive force. The three remaining circuits are leakage circuits.

The corresponding condition in the electric circuit is shown in Fig. 53. Here two E. M. F.'s, shown as batteries connected in series, represent the M. M. F.'s of the magnet coils. These E. M. F.'s send electric flux or current through the four circuits numbered as in the preceding case. The reluctances of the air-gaps are represented by special resistances, a, a. The effect of increasing these resistances a, a, corresponds to lengthening the air-gaps, and causes less current to pass through the keeper

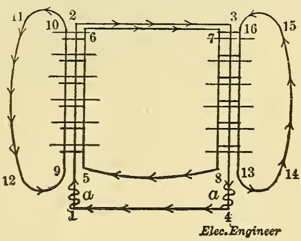


FIG. 53.
Electric analogue of Magnetic Circuit in Fig. 52.

circuit. It may be possible, however, to restore the previous current strength by properly increasing the E. M. F. While this process could be carried on indefinitely in the electric circuit, it is limited in the magnetic circuit, by the fact that the increased flux in the cores ultimately bring up the flux density to an amount at which the reluctance becomes enormous.

138. A non-ferric circuit is shown in Fig. 54, which represents a Kelvin balance, or an ammeter for measuring currents by the electromagnetic attraction of coils carrying these currents.

Here the flux produced by the M. M. F. of the currents

to be measured, has its circuit entirely through air. A diagram representing the magnetic circuits of this apparatus is shown in Fig. 55. Here two horizontal coils

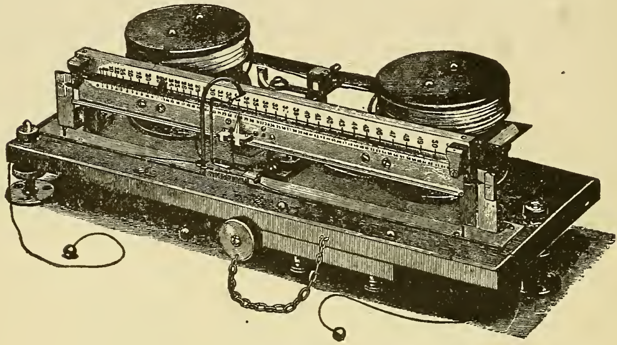


FIG. 54.
Example of Non-Ferric Circuit.

fixed at the ends of a bar A B, which is pivoted on a horizontal axis at the centre O, is free to move, under magnetic forces produced by the current to be measured, through a short vertical distance between the fixed coils C E and D F. When the measured current is sent through all six coils

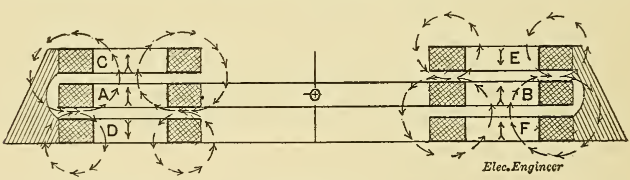


FIG. 55.
Diagram of Kelvin Balance Ammeter, Non-Ferric Circuit.

in series, the flux paths are as roughly indicated by the curved arrows. At each end of the beam, the M. M. F. of the movable coil is in opposition to one, and in conjunc-

tion with the other, of the M. M. F.'s of the fixed coils. The result is an electromagnetic tendency to tilt the beam upwards on the left and downwards on the right, the amount of which can be measured by neutralizing it, by sliding a weight along the beam, thus balancing the magnetic and gravitational forces. Accurate electrical measuring instruments employ non-ferric-magnetic circuits for the reason that the reluctance of these circuits is thereby rendered constant, and that all residual magnetism in the apparatus is avoided.

139. Increasing the magnetic flux in any circuit means increasing the magnetism in that circuit. There are but two known means of increasing magnetic flux in any circuit; namely, by increasing the M. M. F. or by decreasing the reluctance, or by both means combined. To readily increase the flux in a circuit, the strength of the exciting current producing the M. M. F. is usually increased. For example, when it is desired to increase the E. M. F. of a dynamo running at a constant speed, the current passing through its field magnets is usually increased; this produces an increased M. M. F. in the field coils, which in turn produces an increased flux through the circuit and the armature.

140. It has been found by measurement that the reluctance of a joint, or contact between smooth, clean surfaces of soft iron, is about equal to the reluctance of an air-gap between the surface, one six hundredth of an inch in length; but if dirt or rust intervenes, the reluctance of the joint may be much higher, and may be equivalent to the reluctance of a much longer air-gap. It is, therefore, important to ascertain, when mechanic-

ally fitting portions of a ferric magnetic circuit together, as, for example, the yoke to the cores of a dynamo, that the contact surfaces are smooth and clean.

SYLLABUS.

The electric flux in any circuit, in amperes, is equal to the volts divided by the ohms.

The magnetic flux in any circuit, in webers, is equal to the gilberts divided by the oersteds.

In either circuit, any two of these three values being known, the remaining value can be computed.

The flux in any circuit can be increased either by increasing the M. M. F. or by diminishing the reluctance.

In the magnetic circuit of a dynamo, the flux is usually increased by increasing the M. M. F.

In an electromagnet, the flux is increased by diminishing the air-gap reluctance.

Leakage flux is that portion of the flux in a magnetic circuit which does not pass through the device placed in the circuit for the reception of the flux.

Laboratory of Houston & Kennelly,
Philadelphia.

WEEKLY.

No. 15. SEPTEMBER 22, 1894. Price, - 10 Cents. Subscription, $3.00.

Electrical Engineering Leaflets,

—BY—

Prof. E. J. Houston, Ph. D.

AND

A. E. Kennelly, F. R. A. S.

ELEMENTARY GRADE.

ELECTROMAGNETS.

141. If a cylindrical soft iron bar or core be wrapped with an insulated wire or helix, on the passage of an electric current through the wire, the core becomes magnetized with its north pole at one end, and its south pole at the opposite end. If the direction of the current through the magnetizing coil be changed, the direction of polarity will be changed. Moreover, practically, the bar will at once become magnetized on the passage of the current, and will lose its magnetism on the cessation of the current. Such a magnet is called an *electromagnet* in contradistinction to a *permanent magnet*, such as a magnetized bar of hardened steel.

142. The phenomena underlying the production of an electromagnet are readily explained by recalling the following principles already enunciated; namely, (*1.*) An electric current passing through a straight conductor produces a magnetic flux in circular paths about the conductor, as shown in Fig. 56, and the direc-

Published by
THE ELECTRICAL ENGINEER,
203 Broadway, New York N. Y.

[Entered as second-class matter at the New York, N. Y., Post Office, June 14, 1891.]

tion of this circular flux depends on the direction of the current in the wire.

If the current is flowing from the observer, as at A B, the direction of the flux paths is the same as the direction of motion of the hands of a clock; if, on the contrary, the current flows towards the observer, as at C D, the direction of the flux is opposite to the direction of the hands of a clock, or counter-clockwise.

The passage of the current establishes a M. M. F. around the wire, which produces the flux in circular paths.

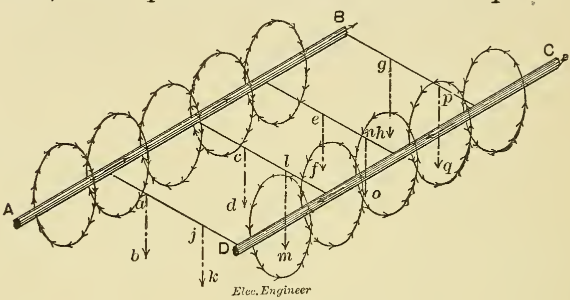


FIG. 56.

Diagram representing the relation of direction of M. M. F. and flux round a wire to the direction of current through the wire.

This is also seen in Fig. 56, where, if the ends B and C, are connected by a wire, a current can flow through A B and return by C D. Within the loop A, B, C, D, all the flux will be directed downwards, as shown by the arrows *a b*, *c d*, etc.

(*2.*) If a straight wire be bent in the form of a single loop, as shown in Fig. 57, and traversed by a current, the M. M. F. produced within the loop, is directed either all downwards, or all upwards, depending on the direction of the current. The flux through the loop takes the paths roughly indicated by the arrows.

(*3.*) A bar of iron brought into a magnetic flux becomes magnetized. If, therefore, the bar be brought within the loop the flux will pass through the bar and magnetize it.

In Fig. 57, the flux from the loop sets up a similarly directed flux in the bar S N, represented by the arrow A B, and the bar becomes magnetized.

(*4.*) That in an electromagnet the flux is assumed to issue at the north-seeking pole and enter at the south-

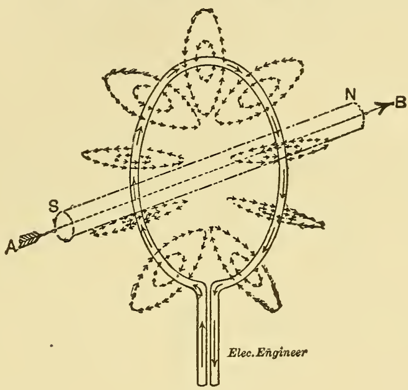


FIG. 57.

Diagram of flux threading a single loop of active conductor, and the effect of this flux upon a bar of iron through the loop.

seeking pole; consequently, the polarity of the bar will vary with the direction of the current through the loop, because the direction of the flux produced by the current depends on the direction of the current.

143. The value of the M. M. F. produced by a single turn will depend on the current strength; if we double the strength of current in the wire, we will double the M. M. F. The same result would be reached if instead of doubling the current strength we passed

the same current strength through two loops in series; for, as we have seen, the M. M. F. depends upon the number of ampere-turns.

144. We can now understand why an insulated conductor wound around a bar produces a north pole at one end of the bar, and a south pole at the other end, and why these change with a change in the direction of the current. An inspection of Fig. 58 will show that if, as at I, the current moves right-handed, or in the direction of the hands of a watch, the north pole will be at the end furthest from the observer; *i.e.*, flux will

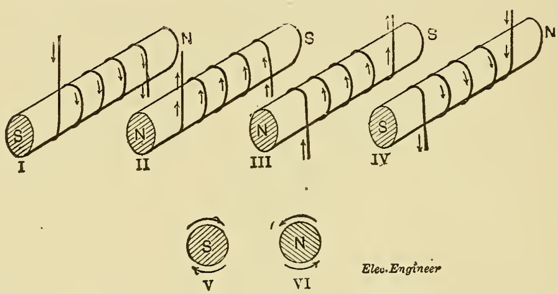


FIG. 58.

Indicating the direction of magnetization in an iron bar as dependent on the direction of winding and of current.

issue there; while, if the direction of the current be changed, as at II, the north pole will be at the end nearest to the observer.

145. The same effect can be produced by changing the direction of winding; *i.e.*, making the helix left-handed, instead of right-handed. Under these circumstances the current entering at III, produces a north pole at the end nearest the observer, and, leaving it at IV, a south pole. All these conditions can be embraced under one simple rule.

The extremities of the letter S, at V, point at each end in the direction of the current which will produce it, and also the extremities of the letter N, at VI, point in the direction of the current which will produce it.

146. Magnets may be divided into the following classes according to the particular character of work required of them.

(*1.*) Tractive magnets, or those possessing considerable power for pulling armatures from a distance.

(*2.*) Portative magnets, or those designed to support heavy weights attached to their armature when once the armature is placed in contact with the poles.

Tractive magnets may be divided into swiftly acting tractive and powerfully acting tractive magnets. The former are intended to act rapidly, as in the case of a telegraph relay, whose armature has to move to-and-fro many times a second. Here the amount of pull exerted by the magnet is comparatively small. Those of the second class are intended to act more slowly, but with considerable force. Such are, for example, semaphore magnets, employed for railroad or other signalling apparatus, where a comparatively heavy weight has to be moved.

147. The tractive power or the portative power of an electromagnet are only indirectly dependent upon the total magnetic flux. They depend directly upon the distribution of the flux density over the polar surfaces. It is possible to take a badly designed portative electromagnet, and to largely increase its portative power by simply altering the area of the polar surfaces, and at the same time diminishing, rather than increasing, the total flux in the circuit. The fundamental law

of electromagnetic attraction is, however, simply expressed as follows: If two flat magnetic surfaces of iron or steel are perpendicularly crossed by magnetic flux, so that the flux leaves one surface and enters the other, then the magnetic attraction of these surfaces per square inch of area can be found in pounds weight by taking the square of the flux density, expressed in gausses, and dividing by 1,730,000. Thus, Fig. 59 represents a cylindrical portative electromagnet, whose keeper is the lower segment of the cylinder not provided with winding. If the length of the cylinder A B, be 10 inches, and the breadth B C, or D E, of the polar surface be 2 inches, then each pole will have an area of 20 square inches in contact with the keeper. Since the magnetic circuit is ferric, and has therefore small reluctance, a powerful current supplied through the winding should generate a considerable M. M. F. in the circuit, and a large flux. Soft iron will practically become saturated, and offer a high reluctance, when the intensity in it reaches 19,000 gausses. If this intensity can be attained all over the polar surfaces, each square inch should exert a force of $\frac{19{,}000 \times 19{,}000}{1{,}730{,}000}$ = about 208 lbs., and, since there are two poles each of 20 sq. inches, the total active surface will be 40 sq. inches, and the total force exerted between poles and keeper will be $40 \times 208 = 8{,}320$ lbs. or about four tons.

148. A powerful portative magnet is, therefore, designed to have as many square inches of saturated polar surface as possible, and the active surfaces are kept smooth and clean to avoid the introduction of unnecessary and prejudicial reluctance at their junctions.

Fig. 60 shows a convenient form of portative magnet of the ironclad type, the external surface being of iron, and the magnetic circuit being developed as shown by the arrows. The number of square inches in the polar surface of the inner core is equal to the number of square inches in the polar surface of the outer shell.

Fig. 61 shows, in plan view, another form of zigzag or multipolar magnet, the winding being led alternately in and out, so as to produce opposite poles successively.

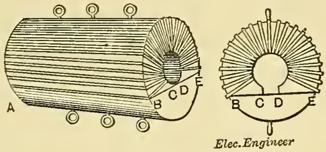


Fig. 59.
Cylindrical Electromagnet.

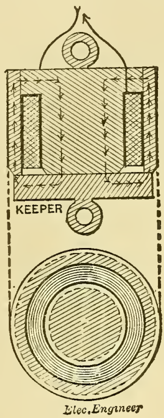


Fig. 60.
Section of Portative Electromagnet through axis, and polar surfaces.

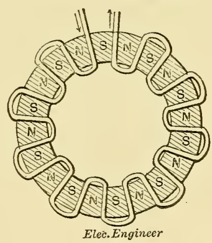


Fig. 61.
Zig-zag or Multiple Magnet.

149. The pull which an electromagnet exerts upon its keeper can be calculated if the magnetic intensity at the poles is known. When the intensity is variable over the polar surfaces, some process of averaging has to be resorted to.

150. When a dynamo or motor has its field magnets excited, these, like any ordinary electromagnet, pull upon the iron core of the armature. The amount

of the pull can be computed from the number of square inches in the polar surface, and the flux intensity existing there. In large machines this pull may be very considerable, and if not properly balanced all round the armature may produce undue wearing in the journals, but, so long as no current passes through the armature, the pulls exerted are radially outwards from the shaft, and there is no tendency to rotate the armature. When, however, current flows through the armature either of a dynamo or motor, the M. M. F. in the armature winding set up by this current, establishes a magnetic circuit and a flux, which, blending with the original flux from the field, destroys the symmetry, and causes a greater intensity at the one polar edge of each magnet, and a lesser intensity at the other polar edge. These differences in intensity set up tractive forces varying as their squares, in such a manner that the armature is pulled round like a keeper towards a magnet if the machine is a motor, and has to be forced round, like a keeper from a magnet, if the machine is a generator. A dynamo machine is therefore a particular kind of rotatory electromagnet.

Syllabus.

A bar of iron introduced into a magnetic flux has a condition of polarity set up in its substance, and becomes magnetized.

Soft iron becomes in this way, temporarily, and hard iron or steel, permanently magnetized.

The direction of magnetization depends upon the direction of the current through the magnetizing coil, and upon the direction in which the coil is wound.

Laboratory of Houston & Kennelly,
Philadelphia.

WEEKLY.

No. 16. SEPTEMBER 29, 1894. Price, - 10 Cents. Subscription, $3.00.

Electrical Engineering Leaflets,

—BY—

Prof. E. J. Houston, Ph. D.
AND
A. E. Kennelly, F. R. A. S.

ELEMENTARY GRADE.

INDUCED E. M. F.

151. If a coil of insulated wire, the ends of which are connected to a galvanometer, be moved across one of the poles of a magnet, an electromotive force will be produced in the coil, and a current will flow through the circuit, as may be shown by a galvanometer. If the motion of the coil be reversed, a current will also be produced, but in the opposite direction. These E. M. F.'s exist only during the motion of the wire, and are called *induced E. M. F.'s.* Since they are produced by the motion of the conductor, this variety of induction is sometimes called *dynamo-electric induction.*

152. If instead of moving the coil of wire past the magnet, the coil be left at rest and the magnet be moved past the coil, then during this motion, an E. M. F. will, as before, be produced in the coil, and the direction of this E. M. F. will reverse when the direction of motion of the magnet is reversed. Since in this case it is the

Published by
THE ELECTRICAL ENGINEER,
203 Broadway, New York N. Y.

[Entered as second-class matter at the New York, N. Y., Post Office, June 14, 1894.]

magnet which is moved, this variety of induction of E. M. F. is sometimes called *magneto-electric induction.*

153. It is evident that in the above cases the production of E. M. F. depends upon the relative motion of the conductor and of the magnetic flux. In both cases the amount of E. M. F. produced will vary with the rate at which either the conductor crosses the magnetic flux or the magnetic flux crosses the conductor. This increase may be obtained for a given coil of wire by either increasing the velocity of motion, or by increasing the intensity of the flux.

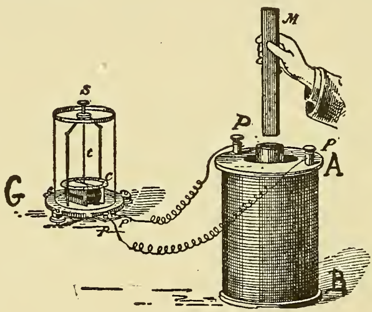


FIG. 62.
Example of Induced E. M. F.

154. The amount of E. M. F. in the wire as measured in volts will depend on the following circumstances; viz. (1), on the speed with which the wire is moving; (2) on the length of the wire; (3) on the intensity of the flux through which the wire moves, as measured in gausses.

155. If, as in Fig. 62, a coil of insulated wire, A B, have its terminals P P′, connected to the galvanometer G, as shown, and a magnet M, be held over the

coil, then if the coil be moved, say, up towards the magnet, the flux from the magnet will enter the coil, and an E. M. F. will be induced in the coil as shown by a movement of the galvanometer needle. If the coil be moved down from the magnet, an E. M. F. is also produced, but this time in the opposite direction. These E. M. F.'s are temporary and exist only during the motion of the coil, that is, when the flux is being poured into or poured out from the loops. This is an instance of an E. M. F. produced by dynamo-electric induction.

If, in the same figure, the coil be left at rest, and the magnet be moved down into the coil, an E. M. F. is produced in the coil, in a certain direction, which would be the same as if the coil were moved up over the magnet, and if the magnet be moved upwards, or out from the coil, an E. M. F. is produced in the coil in the opposite direction. E. M. F.'s so produced are cases of *magneto-electric induction*, and exist only when flux is being poured into or poured out of the loops of a coil.

156. If an E. M. F. induced in a wire is to produce a current, the circuit of the wire must necessarily be closed; or, in other words, a conducting loop must be formed. In no case is an E. M. F. produced unless flux is entering or leaving the loop and in every case the amount of this E. M. F. will depend on the rate at which the loop is being filled with, or emptied of flux, and the direction of the E. M. F. during filling will be opposite to the direction during emptying.

157. When a conducting loop of any size whatever is being filled with, or emptied of, flux at the rate of 100,000,000 webers (100 megawebers) per second, the

E. M. F. induced in the loop at that instant will be one volt. This E. M. F. clearly does not necessarily depend upon the amount of flux that may exist in the loop at that instant, but only upon the rate at which the loop is being filled or emptied ; a very small total flux entering or leaving a loop rapidly may produce in it a higher E. M. F. than a large total flux entering or leaving slowly.

158. When the armature of a dynamo machine is being rapidly revolved in a flux produced through its magnetic circuit by the M. M. F. of its field magnets, the loops of insulated wire on the armature are successively being filled and emptied of flux, that is to say, the flux has first to pass through each loop in one direction, and then, by reason of the rotation of the armature, to pass through the loop in the opposite direction. During the filling of the loop with flux, the E. M. F. induced in the armature loop has one direction, and during the emptying, the direction of E. M. F. in the loop is reversed. For this reason, increasing the speed of revolution of the armature, by making the process of filling and emptying the loops more rapid, increases the E. M. F. generated by the machine. All dynamo electric generators are devices for pouring magnetic flux into, or out of, conducting loops, and, by connecting these loops generally in series, so to suitably combine the induced E. M. F.'s, that a powerful total E. M. F. is produced in an electric circuit.

159. The direction of the E. M. F. induced in a loop by pouring flux into it, or out from it, may be remembered by the following rule :

Considering the loop as a watch, held directly facing

an observer, if the flux pass through the loop in the same direction as the light passes from the watch face to the observer's eye, the E. M. F. *induced around the loop is in the same direction as the motion of the hands of the watch. If the flux be poured into the loop against the direction of the light rays, the* E. M. F. *induced will be against the motion of the hands.*

Emptying flux from a loop is equivalent to filling the loop with flux in the opposite direction.

If, for example, the conducting loop or ring A, Fig. 63, be held at rest in the position 0, then, although, say,

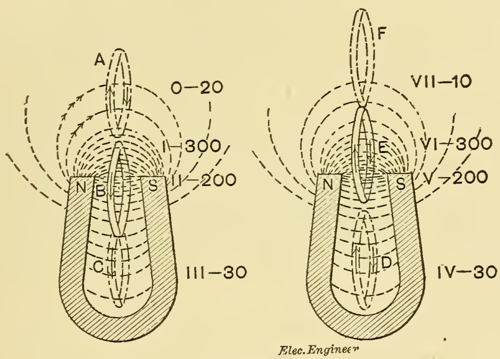


FIG. 63.
Dynamo-Electric Induction,

20 webers of flux pass through the ring, yet since the quantity of flux passing through the loop does not change, no E. M. F. is produced in it. If, however, the loop be moved down towards position II, during this motion, flux pours into the loop, and an E. M. F. is generated, in accordance with the preceding rule, in the direction represented. On arriving at position I, the flux through the loop will have increased to, say, 300 webers, this being the densest part of the field. As

the motion of the loop is continued downwards, the amount of flux will be diminishing, and, consequently, the direction of the E. M. F. at position II, will be changed, as shown by the arrows, and this direction of E. M. F. will be maintained until the loop reaches the lowest position, say, at III, when, perhaps, only 30 webers will be linked with it. If, now, the loop be moved upwards, as at IV, then the amount of flux will be increasing, and the direction of induced E. M. F. will reverse as indicated; and so on through the remaining positions.

160. If the circuit of a voltaic battery be closed through a long coil of wire, no spark is usually seen on closing the circuit. On breaking the circuit, however, a spark may generally be seen accompanied by a distinct sound if the battery be powerful and the coil sufficiently long. This phenomenon is due to an E. M. F. induced in the circuit by the motion of the flux through the circuit when the circuit is broken. We have already seen that any active circuit establishes a M. M. F. and a magnetic flux linked with the circuit. When the circuit is broken this M. M. F. disappears, and the flux linked with the circuit is withdrawn. The cause of the spark seen on breaking is due to the fact that the induced E. M. F. acts in the same direction as the current produced by the battery, and so augments the spark. The induced E. M. F. is also produced when the circuit is closed. Its direction, however, is opposite to the E. M. F. produced by the battery, and tends to oppose the establishment of the current.

This E. M. F. is called an E. M. F. of *induction* and the property of a circuit by which a varying current sets up

an induced E. M. F. is called the *inductance* of the circuit. If an electric circuit be formed of a long coil of wire of many turns, so that the flux is many times linked with the current, the inductance will be large and a single cell may produce an appreciable spark.

If the circuit of a battery be closed through an insulating coil the flux produced therein may link with the circuit of a neighboring conductor or loop, and produce therein an E. M. F.

161. If, for example, the terminals of the voltaic cell in Fig. 64, be connected to a coil of insulated wire, then on the completion of the circuit, an E. M. F. is

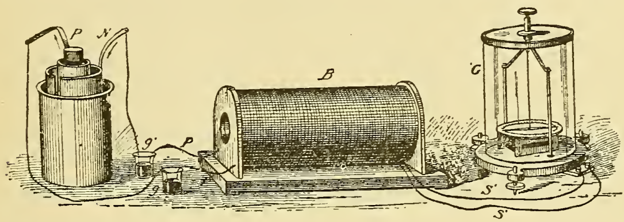


FIG. 64.
E. M. F. by Mutual Induction.

induced in another coil of wire encircling the first coil, as may be seen by the movement of the needle of a galvanometer connected with the terminals of the external coil. Calling the first or inner coil the *primary* coil, and the latter or outer coil the *secondary* coil, then on making the primary circuit, the current in the primary circuit will create a M. M. F. which produces a magnetic flux in the circuit through the coil. This flux pouring through the secondary coil sets up an E. M. F. in it, as indicated by the deflection of the galvanometer needle.

On breaking the primary circuit, the M. M. F. of the primary circuit is destroyed, and the flux is emptied out or disappears from the secondary circuit, setting up in it an E. M. F. in the opposite direction. These E. M. F.'s only exist while the primary current strength is undergoing variations. E. M. F.'s induced in this manner are called E. M. F.'s produced by *mutual induction.*

Syllabus.

Whenever a conducting loop or number of loops is being filled with, or emptied of, flux, an induced E. M. F. is set up in the circuit.

The direction of the induced E. M. F. around any loop coincides with the direction of motion of the hands of a watch if the flux pours into the loop in the direction of light from the face of the watch to the observer's eye.

The value of the induced E. M. F. in a loop at any instant depends upon the rate at which the loop is being emptied of, or filled with, flux. If the rate of filling or emptying be 100 megawebers per second, the E. M. F. at that moment will be one volt.

Four varieties of induced E. M. F. are distinguished; namely:

(*1.*) Dynamo-electric induction. (*2.*) Magneto-electric induction. (*3.*) Self-induction. (*4.*) Mutual-induction.

Laboratory of Houston & Kennelly,
Philadelphia.

WEEKLY.

No. 17. OCTOBER 6, 1894. Price, - 10 Cents. Subscription, $3.00.

Electrical Engineering Leaflets,

—BY—

Prof. E. J. Houston, Ph. D.
AND
A. E. Kennelly, F. R. A. S.

ELEMENTARY GRADE.

THE DYNAMO.

162. We have seen, in the preceding leaflet, that the filling or emptying of a loop with flux produces an E. M. F. around the loop, and that the value of this E. M. F. depends on the rate at which the filling and emptying takes place. We have also seen that the emptying of the loop produces an E. M. F. oppositely directed to that produced by the filling of the loop. If, therefore, a loop be rotated in a magnetic field produced between two opposite poles, it will be filled and emptied twice in each revolution, and, consequently, its E. M. F. will be reversed twice during each revolution.

163. We have also seen that dynamo-electric machines are devices for filling and emptying conducting loops with magnetic flux, and utilizing the E. M. F. induced in such conducting loops, for the production of currents in external circuits.

Ordinarily the part of a dynamo-electric machine, on which the conducting loops are arranged, is called the *ar-*

Published by
THE ELECTRICAL ENGINEER,
203 Broadway, New York N. Y.

[Entered as second-class matter at the New York, N. Y., Post Office, June 14, 1894.]

mature; the device for producing the field flux, is called the *field magnet*, and the device for causing the currents to flow in the same direction, outside the armature, in the

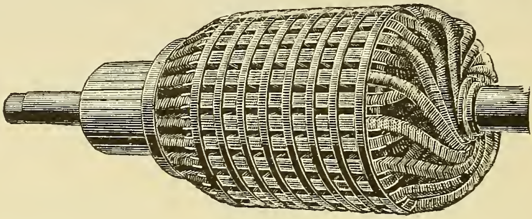


Fig. 65.
Drum Armature.

external circuit, is called the *commutator*. Various arrangements of the conducting loops on the armature have been employed in dynamo-electric machines, but the two in common use are either of the drum or Gramme-ring type. Fig. 65 shows a drum armature, and Fig. 66 a Gramme-ring armature, so called from Gramme, a French electrician, who first practically employed armatures of this character.

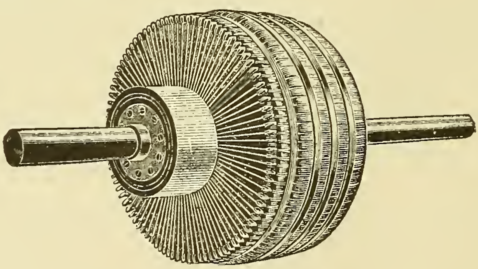


Fig. 66.
Gramme Armature.

164. In order to apply the principles explained in the preceding leaflet to the case of loops arranged on the armature of a dynamo-electric machine, let us

consider the case of two loops of wire C D E F, and G H J K, Fig. 67, arranged at right angles to each other on the armature, and supported on an axis A B, capable of rotation in a bipolar field. In this case the loop G H J K, having its plane lying parallel to the flux, has no flux passing through it; while the loop C D E F, having its plane at right angles to G H J K, is filled with flux. As we have seen, however, the value of the E. M. F. generated, depends not upon the amount of the flux, but upon the rate at which the flux is filling and emptying. It is evident, at the instant shown, therefore, that if we consider the armature rotating, the loop G H J K, will

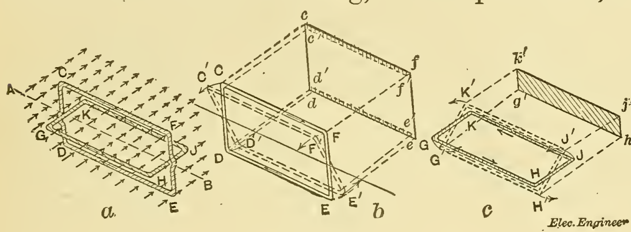


FIG. 67.

have the maximum E. M. F. generated in it, and the loop C D E F, will have no E. M. F. For, suppose the loop C D E F, represented separately in Fig. 67 (*b*), to have been moved by the rotation of the armature during the $\frac{1}{240}$th part of a second, through a small angle shown. During this time it will have passed to the position C′ D′ E′ F′, represented by the dotted lines, and the loop will have emptied out the flux shown by the shaded areas $e\ e'\ d'\ d$, and $f\ c\ c'\ f'$. The flux included in the loop during this fraction of a second may be, say, 102,000 webers; then if the pouring-in continued steadily at this rate for a whole second, the total flux inclosed by the

loop, in that time, would amount to 24,480,000 webers. Dividing this quantity by 100,000,000, to reduce it to volts, the E. M. F. produced is $\frac{2448}{10000}$ volt.

165. The horizontal loop G H J K, in the same fraction of a second, will pour in the amount of flux contained in the shaded strip $g' h' j' k'$, Fig. 67 (*c*). This quantity of flux may be, perhaps, 777,000 webers. If flux were emptied at this rate for a whole second, the total pouring-out would be 186,480,000 webers, and this divided by 100,000,000, shows that the E. M. F. produced in the loop, is $1\frac{86}{100}$ volts. If, however, instead of waiting for the lapse of $\frac{1}{240}$th of a second, we had estimated the rate of emptying by determining the change in the 10,000th part of a second, we should have found the E. M. F. to be much smaller in the vertical loop, and, by taking the interval of time short enough, we should see that no E. M. F. existed in the vertical loop at this instant. As the loop leaves the vertical position where it has no E. M. F., and approaches the horizontal position where it has its maximum E. M. F. (in this case $1\frac{88}{100}$ volts), the E. M. F. constantly rises. As the loop continues in its motion from this horizontal position, the E. M. F. in it diminishes, until, when it is once more vertical, having completed half a revolution, the E. M. F. has disappeared. Continuing its rotation towards the horizontal, the E. M. F. increases, but in the reverse direction, so far as the direction of the wires themselves is concerned, and, finally, on completing the revolution and becoming vertical, the E. M. F. diminishes to zero. For every revolution of the armature the E. M. F. changes direction twice.

166. Fig. 68 represents diagrammatically a Gramme-ring armature, wound with separate turns or loops of wire. The flux enters the armature core at the side A D G, and divides, a part passing through the upper half and the remainder through the lower half, finally leaving the armature at the side A K G. The loops A and G, which stand in the vertical line, are filled with flux, while the loops D and K, have no flux passing through them. As the ring is rotated, E. M. F.'s are induced in these loops, depending upon their rate of filling or emptying with flux. The rings, which at any instant lie horizontally, have the greatest E. M. F., while those which at

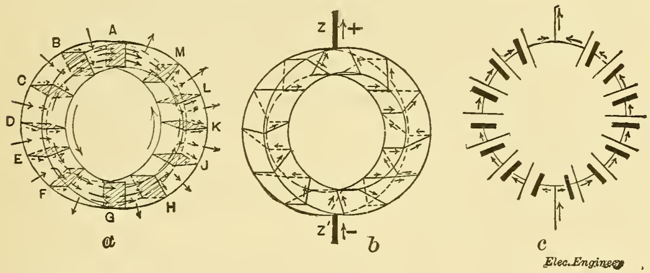


FIG. 68.

any instant occupy the vertical position A G, have no E. M. F. at that moment; at intermediate positions the E. M. F.'s induced in the loops are represented by the arrows.

It will be seen that all the loops on the left hand side of the armature have their E. M. F.'s directed inwards on the face A B C D, and all the loops on the right hand side of the armature are directed outwards on the same face. If these separate loops be all connected in one continuous series, as shown in Fig. 68 (*b*), then the total E. M. F. at any instant will be the sum of the separate E. M. F.'s in the

various loops, and if conducting brushes Z Z′, be applied to the points A and G, so as to be maintained in contact with the wires, as they move beneath, a continuous E. M. F. will be established between the brushes. By connecting the brushes with the external circuit, a continuous current will flow through both sides of the armature in parallel, through the brushes and the external circuit, as represented by the voltaic analogue in Fig. 68 (*c*).

From the foregoing it will appear that the loop A, in passing during its rotation from A to B, will have an E. M. F. generated in it, which will remain in the same direction while passing from B to G, and will be reversed in direction during the remainder of the revolution from G to A.

167. The field magnets of a dynamo are provided for the purpose of establishing the magnetic flux with which the loops on the armature are successively filled and emptied.

The value of the E. M. F. generated by a dynamo depends on three things; *viz.*,

(*1.*) On the total amount of flux which passes through the armature loops.

(*2.*) On the speed with which the armature is rotated; that is to say, the speed with which the loops are successively filled and emptied.

(*3.*) On the number of loops in which E. M. F. is induced and their connection or grouping.

The greater the amount of flux, the greater the number of turns, and the greater the speed of revolution, the greater will be the E. M. F. generated.

168. The output of a dynamo depends not only upon the E. M. F., but also upon the current it can sustain at that E. M. F. The product of the E. M. F. at the

terminals in volts, by the current sustained at full load in amperes, gives the output in watts. It is usual, for convenience, to express the output in kilowatts. Thus a generator producing 750 amperes, at full load, under a pressure at the terminals of 120 volts, produces an output of $750 \times 120 = 90{,}000$ watts $= 90$ KW. If the commercial efficiency of such a machine be 90 per cent., 100 KW. will have to be supplied to the machine at its pulley to drive it at full load, and 100 KW. $\times$ $1.345 = 134.5$ horse power.

The output of a generator is not altered by changing its winding within a fairly wide range. Thus, if the armature be wound with many turns of fine wire, the E. M. F. of the machine will be correspondingly increased, but its resistance will also be increased, and, if the E. M. F. be made, say five times as great, the current it can sustain at full load will be five times diminished. Only when the E. M. F. is made so high that a considerable extra winding space must be devoted to insulation, or when the E. M. F. is so low that considerable space must be devoted to conduction, does the output vary with the winding.

169. The rule for determining the E. M. F. generated by a dynamo-electric machine is as follows: Multiply the total flux in webers, passing through any pole into the armature, by the number of wires upon the surface of the armature, counted once round, and this by the number of revolutions made by the armature per second. The result, divided by 100,000,000, will give the E. M. F. in volts. Thus, suppose a four-pole machine, whose armature has sixty wires lying on its periphery, to make 600 revolutions per minute; *i. e.*, 10 revolutions

per second, and that the flux through each pole in the frame is 10,000,000 webers; then the E. M. F. produced will be

$$\frac{10{,}000{,}000\,(\text{webers}) \times 10\,(\text{revs. per second}) \times 60}{100{,}000{,}000} = 60 \text{ volts.}$$

170. The magnetic circuits of dynamos always employ the best laminated soft iron in their armatures. The field magnets are sometimes of cast iron, sometimes of cast steel, and sometimes of wrought iron, or wrought iron and cast iron combined. Soft iron has the advantage of possessing minimum reluctance, but is expensive to shape. Cast iron is cheapest but produces the highest reluctance, and the cross section must necessarily be enlarged to carry the same flux. Good, soft, open-hearth steel is practically as good as soft Norway iron, and, moreover, can be shaped by moulding. It cannot, however, usually be employed for the smallest sizes of machines, owing to the high temperature at which it is run, to the rapid chilling of small quantities of metal, to the liability to blow holes, and to other difficulties. Very small quantities of impurities in cast iron greatly increase the reluctance produced by a given volume of iron.

Syllabus.

The output of a dynamo is generally estimated in kilowatts, and is obtained by multiplying the pressure in volts which is maintained at its terminals under full load, by the full load current in amperes.

Armatures are generally ring, or drum, wound.

Laboratory of Houston & Kennelly,
Philadelphia.

WEEKLY.

No. 18. OCTOBER 13, 1894. Price, - 10 Cents. Subscription, $3.00.

Electrical Engineering Leaflets,

—BY—

Prof. E. J. Houston, Ph. D.

AND

A. E. Kennelly, F. R. A. S.

ELEMENTARY GRADE.

THE DYNAMO.

171. The output of a dynamo, like that of all other machines, is invariably less than the intake. The output of a dynamo is usually given in kilowatts. Thus, if a dynamo produces 500 amperes at full load, at a pressure of 120 volts measured at its terminals, its output will be (volts $\times$ amperes = watts) $120 \times 500 = 60{,}000$ watts, or 60 KW., or $80\frac{4}{10}$ horse power. This is the external activity which the machine is capable of maintaining at full load.

Suppose now that to drive this machine, an expenditure of 70 KW. is necessary (70 KW. = $93\frac{84}{100}$ H. P.) In other words, while this machine absorbs 70 KW. it gives out as electrical activity only 60 KW. The relation between the output and intake is called the *commercial efficiency* of the machine, and is expressed by a fraction, in which the numerator is the output, and the denominator the intake. In this case $\frac{\text{Output}}{\text{Intake}} = \frac{60}{70} = \frac{6}{7}$

Published by
THE ELECTRICAL ENGINEER,
203 Broadway, New York N. Y.

[Entered as second-class matter at the New York, N. Y., Post Office, June 14, 1894.]

$= 85\frac{7}{10}$ per cent. The efficiency will vary with the character and size of the machine. In generators of one KW., ($1\frac{1}{3}$ H. P.) the efficiency may be as low as 50 per cent., while in very large generators, say, of 1000 KW. capacity, it may be as high as $97\frac{1}{2}$ per cent. It is obvious that the efficiency can never reach 100 per cent.

172. The difference between the value of the output and intake is to be traced to certain losses which occur, whereby energy is uselessly expended in the machine, and does not appear in the external circuit. The lost energy appears in the machine as heat. In other words, other things being equal, the hotter the generator becomes at a given load, the greater will be the loss of energy in the machine, and, consequently, the smaller the efficiency.

173. The sources of loss in dynamo electric machines can be arranged under the following general heads; namely,

(*1.*) Mechanical losses, as the friction of the shaft in its journal bearings, the friction of the brushes on the commutator, and the friction of the rotating armatures against the surrounding air. That is to say, the bearings get warm, the commutator gets warm, and the air gets warm, as previously shown in Fig. 3.

(*2.*) Electrical losses. These are of two distinct kinds; namely, (a), those which occur in the circuit or circuits of the machines, and (b), those which occur in the substance of the copper on the armature, or in the iron of the armature core or pole-pieces. That is to say, the wire on the machine gets warm, and the metal in and around the revolving armature gets warm.

(*3.*) Magnetic losses, or those due to *hysteresis.* That is to say, the iron in the armature, and also, perhaps, in the pole-pieces, gets warm.

174. As regards the mechanical losses from bearing friction, it may be remarked that for a given weight of armature the energy uselessly expended in friction increases with the diameter of the shaft and the velocity of rotation. In other words, to avoid undue friction of this character, the shaft should be made of as small a diameter as is consistent with ample strength. Journal-friction loss also decreases with good lubrication. An inferior lubricant may sensibly increase the journal friction. Similarly the energy wasted in brush friction increases with the number of brushes, the pressure on each brush, the diameter of the commutator, and the speed of rotation. The amount of loss from brush friction, usually insignificant in large dynamos, in very small machines constitutes an appreciable portion of the mechanical losses. Although friction of the rotating armature against the air is a source of loss, yet, since every armature is necessarily heated by the passage through it of the current it generates, a certain amount of air churning is of advantage, as it serves the purpose of ventilating, and thus cooling, the armature.

175. Since the armature of a dynamo possesses a definite resistance, energy will be expended when the current produced by the machine flows through its coils. Thus, if the 60 K. W. generator, above mentioned, has a resistance in its armature of say $\frac{1}{100}$ ohm, the drop, or fall of pressure, in the armature will be $500 \times \frac{1}{100} = 5$ volts, and the energy expended in overcoming the

armature resistance will be the drop multiplied by the current strength, or $5 \times 500 = 2500$ watts. The losses are similarly reckoned in the field magnets, and may amount to 500 watts, so that the electrical losses accounted for in the circuits of this machine are 3000 watts, or 3 KW.

176. During the rotation of the armature, not only are its conducting loops filled and emptied of flux with the induction of E. M. F.'s in them, and the production of useful current in the external circuit, but the masses of metal in the armature and pole pieces are also subject to variations of magnetic flux, and have E. M. F.'s induced in them, which produce local eddy currents, confined to the masses of metal, and therefore, productive of no useful results. The E. M. F.'s so produced are small, yet, since the resistance of the local circuits in which they act is also usually small, the resulting eddy current strengths may be considerable. Besides the eddy currents thus set up in the iron of the machine, similar currents are apt to be produced in the substance of the conducting wires on the armature, if these have considerable cross-sectional area. The remedy is the same in both cases. The masses of metal must be sufficiently subdivided to separate them into a number of separate circuits, each having a reduced E. M. F. and an increased resistance. The armature core is, therefore, laminated in a direction parallel to the flux paths, by building it up of thin sheets of soft iron. If the iron armature core of a large machine were not so subdivided, it might permit the production of eddy currents sufficiently powerful to bring it to a red heat.

The electrical losses, therefore, result in the production

of heat either in the conducting circuit of the machine to an amount depending upon the load, or, in the masses of metal on the machine, to an amount which is practically the same at all loads.

177. The third class of losses, *i. e.*, the magnetic are due to what is called *hysteresis*, (hister-ee′-sis), that is to the fact that the magnetism set up in a piece of iron or steel lags behind the magnetizing flux which produces it. The word hysteresis is derived from the Greek, and signifies *a lagging behind.* When a magnetic flux acts upon a piece of iron or steel, we have seen that the latter becomes magnetized, *i. e.*, that a M. M. F. is established in it, which produces a flux in its own local magnetic circuit. When the original, or magnetizing flux, is withdrawn, the bar does not entirely lose its magnetism, but retains some permanent or residual magnetism. If, therefore, a bar of iron be subjected to alternate reversals of magnetism, so that it is alternately magnetized, demagnetized, and remagnetized in the opposite direction, energy is expended in the process. That is, every cubic inch of iron, subjected to a reversal of magnetic intensity of five kilogausses, requires an expenditure of energy in order to effect the reversal, that would lift it in the case of very soft iron, $\frac{1}{23}$rd inch, or, if very hard steel, through a vertical distance of about one inch. This amount of energy is absorbed at every reversal; consequently, if we double the number of magnetic reversals per second, we double the rate at which energy is being lost by hysteresis, so that a cubic inch of very soft iron, having its magnetic intensity, of say five kilogausses, reversed 250 times per

second, would have energy expended in it sufficient to raise it about 11 inches per second against gravitational force.

178. Energy expended in hysteresis re-appears as heat. In other words, when we successively reverse the magnetism in a piece of iron it becomes hot. The amount of energy absorbed per-reversal-per-cubic-inch, depends both on the quality of the iron, and on the flux density to which its magnetism is carried. Very hard iron or steel may absorb, at each reversal, about 23 times more energy per cubic inch than very soft iron.

If, instead of magnetizing the iron from 5,000 gausses in one direction back to 5,000 in the reverse direction, we increase the flux density to 10,000 gausses in each direction, the amount of energy expended will be practically trebled. In other words, as we increase the intensity of magnetic flux, or the range of intensity in reversal, we increase the energy expended in heating the iron at a greater rate. Doubling the range of reversal, means, practically, trebling the expenditure of energy by hysteresis. For this reason, in actual practice, armatures are seldom magnetized beyond 10 kilogausses.

179. When the bi-polar armature, shown in Fig. 41, is placed in a magnetic flux, its iron is thereby magnetized, say, to an intensity of 10 kilogausses. If now, the armature makes half a revolution, a complete reversal of the direction of its magnetism takes places, the surface which was previously north, *i. e.*, that at which the flux is emerging, (shown on the right hand at *R*,) becomes south, and vice versa. In other words, the magnetic flux from being 10 kilogausses in

one direction, has become changed to 10 kilogausses in the opposite direction; or, has been submitted to a total range of reversal of 20 kilogausses. The hysteretic losses in the armature, therefore, depend upon the number of cubic inches of iron in the armature, the range of magnetic reversal, and the number of reversals per second; *i.e.*, upon the number of revolutions made by the armature per second.

180. Summing up then the losses occurring in the operation of a dynamo, we have:

(*1.*) Losses due to mechanical friction, which are practically the same at all loads on the dynamo, that is to say, whether the machine is delivering no current, or its full activity.

(*2.*) Electrical losses, which, so far as eddy currents are concerned, are nearly the same at all loads.

While the electrical losses in the field-winding are usually slightly increased at full load, owing to the greater exciting current which is then generally allowed to produce them, the electrical loss in the armature winding is usually very small at no load, but increases to a maximum at full load.

(*3.*) Hysteretic loss in the armature is usually nearly as great at no load as at full load, being, at no load, say, 80 per cent. of its full-load value and increases with the load to its maximum, owing to the greater flux density which is usually driven through the armature at full load.

181. If a dynamo-electric machine gets hot at no load, the causes may be, either

(*1.*) A short-circuit in the armature winding, or,

(*2.*) A large loss of energy by eddy currents or hysteresis.

If these various losses are summed and deducted from the intake of the generator, the balance will be the output of the machine, and the ratio of this output to the intake will give the commercial efficiency.

Syllabus.

The electrical efficiency of a generator is the ratio of the external activity to the total electrical activity.

The commercial efficiency is the ratio of the output or external activity, to the intake.

The output of the machine is lower than the intake on account of losses arising from mechanical friction, electrical friction, and magnetic friction.

Hysteresis is the lagging of the magnetization in a magnetic metal behind the magnetizing flux.

Eddy current losses in a dynamo-electric machine increase with the square of the speed of rotation.

Hysteretic loss increases directly with the speed of rotation.

Laboratory of Houston & Kennelly,
Philadelphia.

WEEKLY.

No. 19. OCTOBER 20, 1894. Price, - 10 Cents. Subscription, $3.00.

Electrical Engineering Leaflets,

—BY—

Prof. E. J. Houston, Ph. D.

AND

A. E. Kennelly, F. R. A. S.

ELEMENTARY GRADE.

THE DYNAMO.

182. When a generator is being driven with ample power, it is possible, by increasing the load, to increase the electrical activity in the circuit of the machine very greatly. A limit, however, will be reached in one or more of three ways; namely,

(*1.*) By an excessive drop in the machine, whereby with the maximum E. M. F., which the machine will generate, the pressure remaining at the terminals of the machine will be insufficient to supply the circuit. Thus, if an incandescent circuit supplies lamps of 115 volts, and the fall of pressure in the supply mains be 7 volts, then the pressure required at the terminals of the generator connected with the mains will be 122 volts. If the E. M. F. of the machine was 125 volts, and the drop in the armature, when all the lamps were turned on, was 5 volts, the pressure at generator terminals would only be 120 volts, and the lamps could not be brought to full candle-power. It would be necessary, under

Published by
THE ELECTRICAL ENGINEER,
203 Broadway, New York N. Y.

[Entered as second-class matter at the New York, N. Y., Post Office, June 14, 1894.]

these circumstances, to reduce the load output, or to alter the generator in speed, or otherwise, in order to obtain the required voltage at the lamps.

(2.) By an excessive heating of the machine. We have seen that as the load on a generator increases, the loss of energy in its armature increases, and the armature consequently rises in temperature. If there were no materials in the armature except iron and copper, it might be considered advantageous to operate the dynamo at a temperature slightly below red heat, or just insufficient to ignite inflammable material. Practically, however, all generator armatures have their winding usually insulated with cotton and shellac, or similar materials. It is, therefore, desirable that the highest temperature of the winding should never exceed the boiling point of water (212° F.). In order to secure this condition, under all circumstances of hot dynamo rooms and temporary accidental overloads, it is usual to specify that the highest temperature which a generator shall attain, after a continuous full load run for, say, six hours, shall not exceed that of the surrounding air by more than from 70° F. to 90° F. Conservative practice is reducing this to the lower limit 70° F. This temperature elevation is measured by allowing the machine to operate under full load for a sufficient number of hours, then stopping the machine and placing a thermometer upon the hottest part of the surface under a covering of some non-conducting material, such as cotton waste.

The maximum temperature attained by the thermometer in a period of observation extending over, perhaps, half an hour, is assumed to represent the highest temperature attained by the armature. The rate at

which the temperature of the machine rises, when operated at full load, is greatest at the start and diminishes as time goes on, and its temperature rises. After a sufficiently prolonged run, the temperature remains practically steady. Since, however, heat is constantly being developed in the machine, it is evident that the loss of heat must exactly balance the gain when the temperature becomes steady.

183. The means provided for the loss of heat, which takes place at the surface of the armature, are three; viz.,

(1.) Conduction, whereby heat generated within the armature is carried through the mass of metal to the surface or through the field magnet to the external frame

(2.) Radiation, whereby the heat is thrown out through the air and ether like light. It is by radiation that we can feel the heat without coming in contact with the machine or having the warm air blown upon us; and,

(3.) By convection, or streams of warm air set up from the heated surfaces, by which means the heat is bodily carried away by the air. Of these, the convection losses are much the greatest, and, by suitably ventilating or blowing air through the armature, its temperature can be greatly reduced.

184. (*3.*) By the tendency of the brushes to spark. Every time, during the rotation of the armature, a commutator bar leaves the brush which has rested upon it, a small spark passes between the two. When not excessive, these sparks are in no way prejudicial; but, when excessive, they interfere with the proper

working of the machine, burning the brushes, pitting the commutator, and excessively heating the same. These sparks are due to the counter E. M. F. of self-induction produced in a coil when the current in it is rapidly reversed. For, by reference to Fig. 69, it will be seen that the armature coils on the left hand side of the brush haye their currents in one direction, or downwards, and those on the right hand side, have their currents in the opposite direction, or upwards, so that underneath the brush the current in the coil changes direction. The sudden reversal of this current, if the current is strong, in

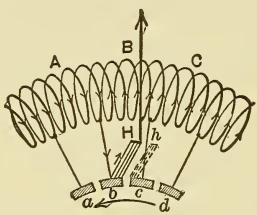


FIG. 69.
Commutation of Segments on the Gramme-Ring Armature.

the long coil of which such segments may be wound, often produces an E. M. F., sufficiently great to cause destructive sparking. In order to reverse the current in the coil, while the brush is short-circuiting it, and to complete this reversal by the moment that the brush has left the bar, it is usual, to give the brushes a *lead*, that is, to move them forward on the commutator in the direction in which the armature is running, with the object of bringing the coil, which is being short-circuited, into the action of the flux from the field magnets, so that the emptying of this flux produces the right direction of E. M. F. in the coil to reverse the current while the short-

circuit lasts. In most machines, therefore, the lead of the brushes has to be increased as the load increases, in order to set up a greater E. M. F. in the coils as they are short-circuited, and in some machines this is done automatically.

Toothed-core machines can be designed to give considerably less sparking than smooth core machines at the same full load output.

185. Some dynamo armatures vibrate excessively during rotation. This is usually from want of mechanical balance. If the weight of the armature is not uniformly distributed about the axis of the shaft, there will be a tendency for the side that is heavy to bring irregular pressure to bear upon the journals during rotation, and the reaction so produced sets the whole armature in vibration. In order to avoid this difficulty it is only necessary to balance the armature mechanically, by resting its shaft across two smooth parallel and level bars of steel, and observing whether the armature remains at rest in any position. If one side is heavier than another, that side tends to rotate the armature and descends to the lowest point. The lighter side has, therefore, to be weighted with properly secured metallic masses and the experiment repeated until balance is obtained.

186. When a machine, of, say, 100 KW. capacity, can be made either for belt-driving or direct-driving, it is generally more economical in first cost to construct it belt-driven, since, for mechanical reasons, the speed of rotation of the armature is usually less with a direct-coupled machine than with a belt-driven machine. And, since the E. M. F. generated by a dynamo increases

directly with the speed, a slow speed necessitates a larger generator, other things being equal. Where, however, space is limited, and durability is a matter of importance, preference may be given to direct driven generators, which avoid the wear of the belt and the space it requires. Belt speeds vary in practice between 2,500 and 6,300 feet per minute.

187. When a number of generators, driven by separate engines, are connected in multiple, as, for example, in a low tension station, a close regulation or governing of the engine is a matter of considerable importance; for, if the drop in each machine is 3 per cent. of the pressure at its terminals, when the load is equally shared among the machines, it will only require a reduction in speed of the engine of any generator, to an amount exceeding three per cent., to bring the pressure at its terminals greater than the E. M. F. produced by the machine, unless specially controlled, and, under these conditions, the dynamo is liable to act as a motor, and instead of taking power from the engine, to drive the engine at the expense of power from the other generators.

188. The exercise of care in the operation of the brushes and commutators will generally greatly prolong their lives. The brushes should always be carefully set at the right relative positions to each other; exactly opposite each other in bipolar machines; at exact quadrants in quadripolar machines; at exact sextants in six-pole machines, and so on, and this setting can best be accomplished by counting the commutator bars between the points of the brushes. The pressure brought to bear on the brushes should be as light as is consistent

with efficient contact. The contact between brush and brush holder should be clean, since imperfect contact, through oil or dirt in the circuit of the brushes, is very apt to produce undue resistance and heating. The commutator surface should be wiped occasionally to remove particles of copper-dust which might accumulate detrimentally.

189. Carbon brushes have come into extended use, in all but low tension generators, for the reason that they wear uniformly, are solid instead of laminated, lubricate the commutator instead of scratching it, and considerably reduce the effects of sparking, since the carbon is more apt to burn away in sparks than copper on the commutator. The resistance of such brushes is very high compared with copper, and this interferes with their employment for very large currents.

Syllabus.

The electrical activity of a machine is limited by three considerations.

(1.) By excessive drop of pressure in the machine which prevents the delivery of the required pressure at the terminals.

(2.) By an excessive heating of the machine, which, besides increasing the resistance and drop in the machine, may threaten to destroy the insulation of its winding.

(3.) By an excessive sparking, which tends to destroy the commutator.

In practice the circuit of dynamos is so proportioned that the temperature of the machine, after continuous

full load run, shall not exceed that of the surrounding air from 70 to 90 degrees Fahrenheit.

The heat generated in a machine is dissipated in three ways.

(1.) By conduction.

(2.) By radiation.

(3.) By convection.

The latter is the most important in the practical opertion of the machine.

Sparking at the commutator of a machine is due to the sudden reversal of a current in each armature coil under the brush. Under certain conditions, in order to decrease the sparking, a lead or forward motion is given to the brushes.

Laboratory of Houston & Kennelly,
Philadelphia.

WEEKLY.

No. 20. October 27, 1894. Price, - 10 Cents. Subscription, $3.00.

Electrical Engineering Leaflets,

—BY—

Prof. E. J. Houston, Ph. D.

AND

A. E. Kennelly, F. R. A. S.

ELEMENTARY GRADE.

The Regulation of the Dynamo.

190. Most commercial electric circuits are either series circuits or parallel circuits. The former are generally employed for series-arc lighting; the latter for continous-multiple-incandescent lighting. Fig. 70 represents the connections of a series-wound generator, *i.e.*, a generator whose field-magnet coil M, is in series with the armature A, and which, therefore, receives its M. M. F. from the current in the main circuit. A series-wound 60 arc-light dynamo must provide the same current for each of the arc lights that may be in its circuit, from one, up to, say, the full load of 60 lights; and, in order to do this, as additional lights are introduced into the circuit, the E. M. F. must be correspondingly increased. A single arc lamp may require, say, 50 volts at its terminals, while 60 lamps in series would require 60 times as much, or 3,000 volts.

191. We have seen that the E. M. F. generated by a dynamo can be varied in four ways; *viz.*, by varying the speed of rotation; by varying the number of

Published by
THE ELECTRICAL ENGINEER,
203 Broadway, New York, N. Y.

[Entered as second-class matter at the New York, N. Y., Post Office, June 14, 1894.]

conductors on the armature; by varying the magnetic flux passing through the armature, and by varying the position of the brushes on the commutator. Since the number of conductors on the armature remains constant, and since the speed is usually unchanged, there remains but the change of magnetic flux, or the change in the position of the brushes. Series-arc lighting dynamos, in order to increase the E. M. F. necessary for an increase of load, in nearly all cases shift their brushes, either automatically, or by hand.

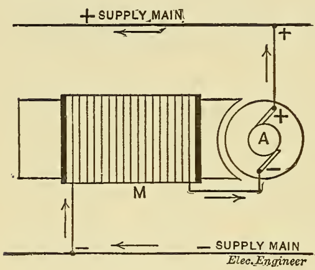


FIG. 70.
Series-wound generator.

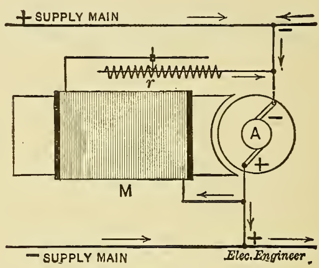


FIG. 71.
Shunt-wound generator.

192. Generators for incandescent circuits are frequently shunt-wound; that is to say, their magnets are not connected in series with the armature, but are connected at the brushes in shunt with the external circuit. By this means a portion of the armature current is always employed for developing the M. M. F. required in the field magnets.

Fig. 71 represents diagrammatically the connections of a shunt-wound generator. The circuit of the field magnet is provided with a rheostat, or adjustable resistance r, by means of which the M. M. F. of the field magnets can be varied by regulating the current strength

in the circuit. If a generator of 60 KW. capacity has to supply an incandescent circuit at a pressure of 120 volts at its terminals, its full load will be 500 amperes. Supposing that 10 amperes are required in the field circuit at full load, the resistance of the field circuit, including such portion of the rheostat as may then remain in the circuit, will be 12 ohms, and the total current through the armature will be 510 amperes. If the resistance of the armature be $\frac{12}{1020}$ ohm, the drop in the armature at full load will be, volts = amperes $\times$ ohms = 510 $\times \frac{12}{1020} = 6$ volts. The E. M. F. of the machine must, therefore, be 126 volts in order to supply 120 volts at its terminals. At a very small load, when, say, only a few lamps are left connected with the circuit, the pressure at the terminals would rise to nearly 126 volts, unless the M. M. F. of the field magnet coils be reduced by the introduction of additional resistance at r. It is evident that since the pressure at terminals cannot vary between full load and no load, by more than, say, about 10 volts, even if no regulation were attempted, the M. M. F. of the field magnets can only vary in that proportion. Assuming, however, that by means of regulation the terminal pressure is maintained at 120 volts, the current in the field circuit will be this pressure divided by the total resistance of the magnet coils and rheostat.

193. When it is desired to discard hand-regulation and to make the generator automatically regulating, the method of compound-winding is employed. We have seen that a series-wound machine tends to increase its M. M. F. and consequently its E. M. F. on an increase of load, and that, on the contrary, a shunt-wound machine, owing to drop in the armature circuit, tends to decrease

its M. M. F., and consequently its E. M. F. on such increase of load. By suitably combining both these forms of winding on the field magnets of the generator, that is, by making a generator *compound-wound*, these two opposite tendencies can be made to balance each other, and the machine thus be rendered self-regulating. Fig. 72 shows diagrammatically the connections of a compound-wound generator in which the magnets coils are partly excited by a shunt-winding taken from the brushes, and partly by a series-winding in the main circuit. If, for example, a 100 KW. compound-wound generator has to maintain a constant terminal pressure of 500 volts, its

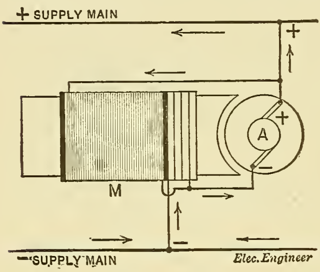


FIG. 72.
Compound-wound generator.

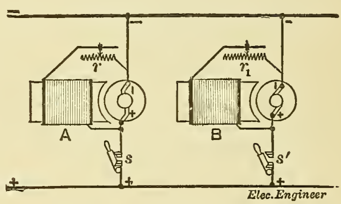


FIG. 73.
Connections of two hand regulated shunt wound generators in parallel.

full-load current will be 200 amperes. If its resistance be $\frac{1}{20}$th ohm, and the resistance of its shunt-winding be 500 ohms, one ampere will flow steadily through the shunt-windings at all loads. If this winding consists of 10,000 ampere-turns of wire, there will be a M. M. F. of 10,000 ampere-turns. The drop in the resistance of the machine will be $501 \times \frac{1}{20} = 25\frac{1}{20}$ volts. In order to increase the E. M. F. of the armature by this amount, it may be necessary to increase the M. M. F. to, say, 12,000 ampere-turns, that is, to introduce 2,000

ampere-turns additional M. M. F. If, therefore, the series-winding be composed of 10 turns in all, its M. M. F. will be at full load $10 \times 200 = 2{,}000$ ampere-turns, the amount required. It is evident that since the total resistance of this series winding on the armature does not exceed $\frac{1}{20}$th ohm, the series-winding must be of very stout wire.

194. It is sometimes required that the pressure supplied by a generator shall remain constant, not at its terminals, but at the terminals of delivery, which may be half a mile or more away from the generator, and separated from it by the total resistance of the leads or supply mains. In this case the resistance of the mains has to be considered as virtually added to the resistance of the armature, and the series-winding accomodated to compensate for the additional drop in the supply mains. Such a generator is said to be *over-compounded.*

195. In practice, owing to the variations of load in distributing systems of light or power at different hours of the day, the generator plant is divided into suitable units, and these units are usually arranged for connection in parallel with the *bus-bars*, or main terminals of the central-station. In low-tension lighting systems, the generators are usually shunt-wound, for the reason that since tension is necessary to maintain the pressure uniform at the lamps, the additional attention required for regulating the generators adds very little to the labor of operation, and also ensures the safety of the generators in case of a short circuit or violent overload. In case of such accident, the tendency of the shunt-wound machines, owing to excessive drop in the armature, will be to lose

their M. M. F. and thus diminish their excessive output. In street railway systems the generators on the other hand are usually compound-wound, partly because the pressure does not require to be regulated within such close limits as incandescent lighting demands, and partly because the sudden fluctuations in load, which are inherent to railway systems, are automatically regulated by the generators.

196. Fig. 73 represents, diagrammatically, the connections of two shunt-wound machines arranged for operation in parallel. The method adopted is as follows: One machine, say A, is first started by running its engine up to speed, cutting out all resistance in the rheostat r, and allowing the residual magnetic flux in the magnetic circuit to generate an E. M. F. in the armature. Under the influence of this E. M. F., the current passes through the field coil, generating a M. M. F., which, in its turn, increases the E. M. F. of the armature. This interaction between the electric and magnetic circuit results in rapidly *building up* the E. M. F. of the generator, until the standard pressure is attained. At the moment the correct resistance is found in the rheostat, at which the pressure, as indicated by a voltmeter, is the pressure required on the mains, the switch s, is closed, thus connecting the machine with the mains. When the load increases beyond the capacity of the generator A, the generator B, is similarly introduced into the circuit of the bus-bars as soon as its pressure is approximately equal to that between them. If the pressure at B, at the moment of closing the switch, be exactly equal to the bus-bar pressure, no current will flow through the armature of B, into the circuit, as will be indicated by its ammeter; but,

by slightly increasing the M. M. F. of B, through the reduction of the resistance in the rheostat r, its E. M. F. may be increased until the load is evenly divided between the two generators.

197. The closeness of the regulation of the pressure at the terminals of dynamos, varies with the kind of work which the receptive devices in the circuit have to perform. In arc-light dynamos the regulation must be within the limits which the arc-lamp mechanism can accommodate, and may be, say, five per cent. above or below the normal. In incandescent lighting the limit is much closer. A regular 16 C. P. 115 volt $\frac{437}{1000}$ ampere, 50 watt incandescent lamp, if operated at 116 volts, *i.e.*, at one volt in excess of the normal, will give $16\frac{9}{10}$ initial candle power, and reduce its probable lifetime $17\frac{1}{2}$ per cent., while if operated at 117 volts, its initial candle power will be $17\frac{8}{10}$ candle power, and its probable reduction of life 33 per cent. Correspondingly marked diminution of candle power and increase in life will accompany a reduction in pressure below the normal, so that greater care is required in the regulation of incandescent dynamos than in those of any other type. In railroad generators supplying 500 volts, the effect of variation in pressure is only to alter the speed of the cars on the track, and variations amounting to 10 per cent. at the motor terminals are not objectionable so far as the motors alone are concerned. In power circuits devoted to the operation of motors for driving machinery, variations in pressure may be productive of variations in speed, which, for many classes of work is very objectionable, so that such generators are usually compound-wound.

Syllabus.

Most practical generators are either series-wound, shunt-wound, or compound-wound.

A series-wound generator can be regulated to supply a varying E. M. F. according to the position of its brushes.

A shunt-wound generator can be made to supply a varying current at a constant pressure by regulating the strength of the current through its fields, *i.e.*, its M. M. F.

A compound-wound generator can be made to maintain automatically its pressure constant at all loads between no load and full load.

Laboratory of Houston & Kennelly,
Philadelphia.

WEEKLY.

No. 21. NOVEMBER 3, 1894. Price, - 10 Cents. Subscription, $3.00.

Electrical Engineering Leaflets,

—BY—

Prof. E. J. Houston, Ph. D.
AND
A. E. Kennelly, F. R. A. S.

ELEMENTARY GRADE.

ELECTRODYNAMICS.

198. When a conductor, conveying an electric current, is placed across a magnetic flux, such, for example, as the uniform magnetic flux shown in Fig. 74, a mutual action between the flux produced by the current in the conductor, and the flux in which it is placed, produces a force tending to move the wire in the downward direction shown by the large arrow O C. This force is called the *electrodynamic force.* The current in the wire, as already pointed out in Fig. 56, produces flux around it in concentric circles. When a current is flowing through the wire A B, from A to B, in the direction of the arrow, the direction of the circular flux produced around the conductor, is such that the flux-paths take the same direction as the external flux above the conductor, and in the opposite direction below the conductor; therefore, the resultant flux is greater above the conductor, where the two fluxes aid one another, and smaller below the conductor, where they tend to oppose and neutralize. The conduc-

Published by
THE ELECTRICAL ENGINEER,
203 Broadway, New York, N. Y.

[Entered as second-class matter at the New York, N. Y., Post Office, June 14, 1894.]

tor moves, or tends to move, from the stronger towards the weaker flux.

199. In order that a current should be sent through a conductor, it is necessary to form a complete circuit or loop. If placed in an external magnetic flux, all parts of this loop will be subjected to electrodynamic forces. The general tendency of the motion so produced will always be to move the loop into such a position as will enable it to have passed through it as much external flux as possible. For example, if the rectangular

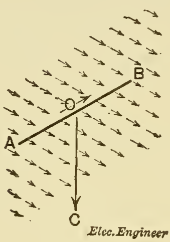


Fig. 74.

Diagram indicating the direction of the electromagnetic force on an active conductor lying across a uniform magnetic flux.

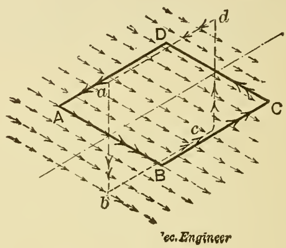


Fig. 75.

Diagram of rectangle of active conductor A B C D, situated in a uniform magnetic flux.

loop A B C D, Fig. 75, traversed by a current in the direction indicated by the arrows, be placed in the uniform external magnetic flux indicated, the tendency of the forces, exerted electrodynamically on the conductor, will be to bring the loop into the vertical position *a b c d*, in which it will embrace the greatest amount of external flux that can pass through it in the same direction as its own flux. The loop of active conductor, i.e., the conductor carrying the current, always tends to set itself in such a direction as to embrace as much flux as possible, and the force producing the motion ceases as

soon as any small displacement of the loops fails to introduce in it a further quantity of flux. The amount of work done by the loop, in moving between the two positions shown, will depend upon the strength of the current through the loop, and on the total amount of external flux introduced into it by the motion.

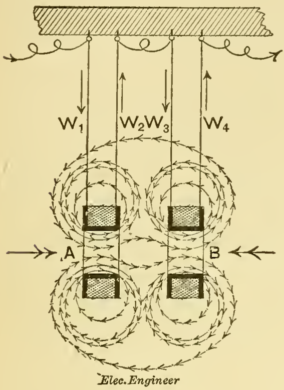


FIG. 76.

Diagrammatic representation of the flux established in surrounding air by the M. M. F. of two equal active coils of insulated wire.

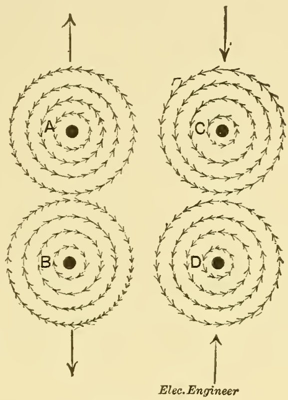


FIG. 77.

Sections of wires with diagrammatic distribution of flux.

In A current towards observer.

In B current from observer.

In A and B currents in opposite directions, repelling.

In C current towards observer.

In D current towards observer.

In C and D currents in same direction, attractive.

200. Fig. 76, represents two coils of insulated wire, supported from a beam by conducting wires, and connected in series with an electric source, which causes the current to flow through them in the direction indicated by the large arrows. The magnetic fluxes produced in the coils by their M. M. F. are roughly indicated by the curved arrow-paths. Under these circumstances the electrodynamic force causes the loops to approach each other;

i.e., to attract each other, so as to cause the loops to embrace more and more of each other's flux. Each turn of the coil A, will singly exert an attractive force upon the coil B, depending on the strength of the current, and on the amount of B's flux which it can enclose by the motion, so that, the current strength remaining the same, by winding a number of turns on the coil, the total attractive force may be correspondingly increased. If the direction of the current in one of the coils be reversed, the coils will repel each other, because, although the effect of their approach would be to cause them to embrace more of each other's flux, yet this flux is now oppositely directed to that produced by their own M. M. F. The application of this principle is shown in the Kelvin balance ammeter in Figs. 54 and 55, where the strength of the current passing through the coils is measured by weighing the amount of their attraction and repulsion.

201. If a small, freely suspended compass needle be held beneath and close to a wire carrying a current, the mutual action between the flux produced by the current, and the flux produced by the needle, will produce a force upon the needle which will tend to set it at right angles to the wire, and the needle will come to rest in the position at which the flux from its own M. M. F. passes through its substance in the same direction as the combined external flux from the wire and from the earth's magnetism. If, however, the needle be held above and close to the wire, the mutual action of the flux produced by the current and the flux produced by the needle will be reversed, i.e., the needle will still tend to set itself at right angles to the wire, and parallel to the direction of the flux around the wire, but the

direction in which it has to move to do this will be reversed, as will be evident from an examination of Figs. 40 and 56. Similarly, if with the needle placed either above or below the conductor, the direction of the current in the conductor be reversed, the direction of the needle's motion will be reversed. Generally then, the fluxes produced at the same point by separate sources tend to become parallel, whether produced from separate active conductors, or from magnets and conductors, or from magnets and magnets. Thus, when two magnets attract each other, they tend to assume such a position of rest, that the flux of each passes through the other in the same direction as its own flux, and, in order to do this, their opposite poles must be opposed.

202. In a continuous-current electromagnetic motor, continuous rotation is obtained by the action of electrodynamic forces on conducting loops, supported on a movable part called the armature, and set at uniform angular distances apart. These loops are placed in a powerful magnetic flux produced by the field magnets. Each loop of conductor, when excited by the current which drives the motor, tends to move into the position at which it encloses the greatest amount of flux produced by the field magnets. The direction in which each loop tends to move, is that in which it will bring the flux due to its own M. M. F. parallel to the external flux from the field magnets, and the force with which it tends to move, depends upon the strength of the current in the loop; i.e., on the strength of the current driving the motor, and on the amount of flux which can be linked with the conductor, that is, on the size of the loop and on the density of the flux within it. As soon as each loop arrives

at that position in which it embraces a maximum field flux, the force urging it forward ceases, and, if it were then advanced beyond this position, the electrodynamic force produced would be reversed, and would tend to bring back the loop to the position of maximum embraced flux. Consequently, it is necessary, in order to obtain a continuous rotary motion of the armature, to reverse the current through such loops at the moment when they arrive at the position when the force upon them ceases, and this is brought about in practice by the action of the commutator.

203. A variety of motions may, therefore, be produced by the mutual interaction of the flux attending active conductors. These may be embraced under the following general laws; namely,

(*1.*) Currents flowing in the same direction attract one another.

(*2.*) Currents flowing in opposite directions repel one another. See Fig. 77.

Besides the explanations already given of the causes of such attractions and repulsions, it may serve to aid the memory as to whether attraction or repulsion will take place in any given case, to observe, that if the directions of the flux are traced, then when currents flow through conductors in the same direction, the fluxes will lie in opposite directions between the conductors, while, if the currents flow in the opposite directions, the fluxes between the conductors will lie in the same direction. So that oppositely directed fluxes attract and similarly directed fluxes repel.

204. Although an electrodynamic force is invariably produced by the mutual interaction of magnetic fluxes, attending a flow of current through neighbor-

ing conductors, yet the amount of such force is so small that it is never employed in practice. Even when this force is multiplied by winding many turns of conductor into coils, such as shown in Fig. 76, the amount of the force is ordinarily so small that it is only practically employed in measuring instruments, where the work to be done is very limited. In order to apply electrodynamic force for industrial purposes, as in motors, is is necessary to greatly increase the flux by the introduction of iron into the magnetic circuit of the coils. Under these circumstances very powerful electrodynamic forces may be readily obtained. Thus, we have already seen that electromagnets can be made which will support over 200 pounds weight per square inch of polar surface. The attractive force between an electromagnet and its armature is but a variety of electrodynamic force.

Another illustration of electrodynamic force is seen in the well known tendency of a freely suspended needle to point approximately towards the geographical North pole of the earth. The earth acts as a huge magnet; i. e., possesses a M. M. F., which causes a magnetic flux to be distributed over its entire surface. Under the mutual action between the earth's flux and the flux in the magnetic circuit of the needle, electrodynamic forces are set up which tend to move the needle to a position in which the flux within its substance is parallel to the earth's flux. Strictly speaking, such electrodynamic forces would be more properly termed magnetodynamic forces.

205. Like all work, the work done by electrodynamic forces, has to be supplied from some source of energy, and here is always supplied from electric source, producing the current or currents in the conductor upon

which the force is exerted. We have seen that the motion of a conductor through a magnetic flux induces an E. M. F. in the conductor, and, consequently, the motion of any active conductor through a magnetic flux under electrodynamic force, induces an E. M. F. in the conductor, which is always opposed to the direction of the current. This opposition of E. M. F. to a current, always absorbs energy from the current, which has to be supplied by the electromotive source; i. e., the battery, dynamo or other electric source supplying the circuit.

Syllabus.

Electrodynamics is that branch of electromagnetism which treats of the attractions and repulsions of magnetic fluxes.

When two separate M. M. F.'s set up independent fluxes, these fluxes tend to align themselves, and the force with which they do this is called electrodynamic force.

If either of the sources of M. M. F. be movable, the electrodynamic force will produce such a motion in it as will set the fluxes in parallelism.

The work which an active conducting loop will perform under electrodynamic forces depends upon the strength of the current in the loop and upon the amount of flux it can enclose.

An electromagnetic motor is a device for producing continuous rotation from electrodynamic forces exerted between the flux produced by field magnets, and the flux produced by active conducting loops on the armature.

Laboratory of Houston & Kennelly,
Philadelphia.

WEEKLY.

No. 22. NOVEMBER 10, 1894. Price, - 10 Cents. Subscription, $3.00.

Electrical Engineering Leaflets,

—BY—

Prof. E. J. Houston, Ph. D.
AND
A. E. Kennelly, F. R. A. S.

ELEMENTARY GRADE.

THE ELECTRIC MOTOR.

(CONTINUOUS CURRENT TYPE.)

206. We have seen, in a dynamo-electric generator, that in order to generate E. M. F. in the conducting loops on the armature, by successively filling them with and emptying them of the flux from the field magnets, the armature must be rotated; and, when this E. M. F. is producing a current in the armature and circuit, it is necessary to apply considerable force to the pulley of the dynamo. This force is required to revolve the armature against the electrodynamic forces set up by the active conducting loops on its surface, by the interaction of their flux and the flux from the field magnets. The work done by this force supplies to the generator the energy it expends electrically in its circuit.

207. Similarly, when an electric motor, such as is represented in Fig. 78, is supplied with an electric current to drive it, the loops of active conductor on its armature A, are rotated under the influence of the electrodynamic force, produced by the interaction of their

Published by
THE ELECTRICAL ENGINEER,
203 Broadway, New York, N. Y.

[Entered as second-class matter at the New York, N. Y., Post Office, June 14, 1894.]

flux and that from the field magnets M, M[1]. The rotation of the armature loops, however, through the field-flux, sets up in them an E. M. F. just as though the armature were being driven at the same speed by a belt, except that this E. M. F., instead of driving the current through the armature and the external circuit, as in the case of a

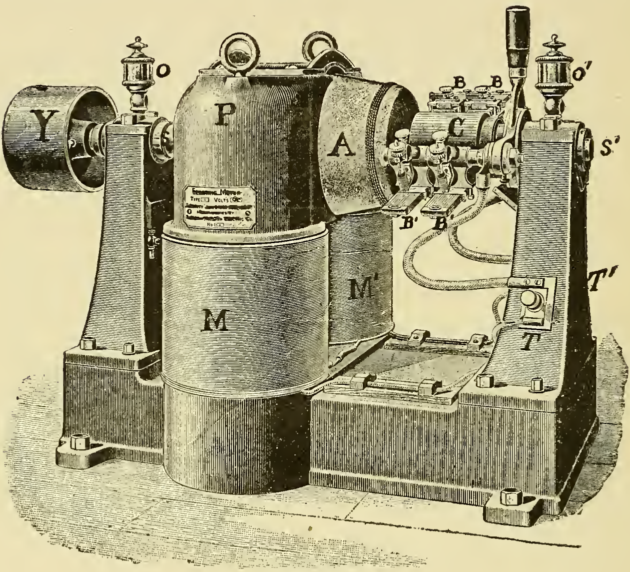


Fig. 78.

dynamo, is opposed to the direction of the driving current in the motor, and is, therefore, called the *counter E. M. F.*, usually abbreviated C. E. M. F.

208. A dynamo and a motor are reversible machines.

In the dynamo, mechanical force is applied against counter-electrodynamic force, and the E. M. F. produced in the armature is always greater than the pressure at the

terminals of the machine, owing to the drop in the armature resistance. In the motor, the electrodynamic force is directly applied to produce rotation against the load which the motor has to drive, and the C. E. M. F. of the machine is always less than the pressure at the machine terminals, by the drop in the resistance of the machine, and, represented in volts by the product of the amperes and the internal resistance in ohms.

Or, as may be expressed in tabular form:

DYNAMO.	MOTOR.
Mechanical force equal and opposite to counter electrodynamic force.	Electrodynamic force equal to opposed mechanical forces of driven machinery.
E. M. F. of machine greater than terminal pressure.	C. E. M. F. of machine less than terminal pressure.

Fig. 79 diagrammatically represents the use of two similar electrodynamic machines in the transmission of 20 KW. from an engine to a line shaft at a distance of a mile.

109. Just as the work yielded by a dynamo in the form of electrical energy in its circuit, represented by the product of the volts and amperes, has to be derived from the engine driving it, so the work yielded by a motor, in the form of mechanical energy at its pulley, has to be derived from the electrical energy absorbed by the machine at its terminals, and represented by the product of the volts and amperes. Thus, if the motor shown in Fig. 78 gives mechanical energy at its belt and pulley Y, amounting to say 10 KW. ($13\frac{4}{10}$ H. P.), more than this amount of energy, say 13 KW. of electrical energy, would have to be supplied to the motor at its terminals T, T^1, in order to drive it. If, for example, the pressure at the motor terminals were 130 volts, the

current supplied to the motor would be, say, 100 amperes (130 volts $\times$ 100 amperes $=$ 13,000 watts $=$ 13 KW.) and the efficiency of the motor would be, output divided by intake $= \frac{10}{13} =$ very nearly $\frac{77}{100}$, or 77 per cent.

It is evident from the figure that the field magnets M, M^1, are connected in parallel or in shunt with the

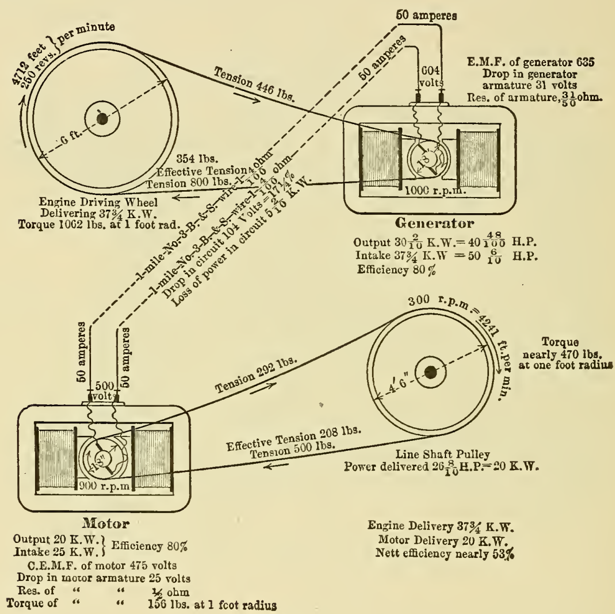


FIG. 79.

armature A, so that the machine is a shunt motor. If, say five amperes, are diverted through the shunt-path of the field magnets, the remainder of the current, or 96 amperes will, at full load, pass through the armature. Supposing that the resistance of the armature, including the commutator C, and brushes B, B^1, to be $\frac{1}{20}$ ohm, the

drop of pressure in the armature will be the current in amperes multiplied by the resistance in ohms, or $96 \times \frac{1}{20} = 4\frac{16}{20}$ volts, and the C. E. M. F. of the armature must be the balance of this from the terminal pressure of 130 volts, namely, $125\frac{4}{20}$ volts. This C. E. M. F. must be produced in accordance with the principles already explained in connection with revolving armatures in dynamos; namely, that the E. M. F. is equal (see Sec. 169) to the product of the total flux through one pole in webers, the number of wires on the surface of the armature counted once around, and the number of revolutions made by the armature per second, divided by 100,000,000. If, for example, in the above machine, the number of wires on the surface of the armature, counted once around, is 250, and if the useful magnetic flux passing through one pole, into or out of the armature, be 3,130,000 webers, the speed of the armature must be 16 revolutions per second, or 960 revolutions per minute, since,

$$\frac{3{,}130{,}000 \text{ (webers)} \times 16 \text{ (revs. per sec.)} \times 250}{100{,}000{,}000} = 125\tfrac{4}{20} \text{ volts.}$$

If now, the load on the motor be decreased so that the motor is enabled to rotate faster, the C. E. M. F. will increase say to 128 volts, and a weaker current will, therefore, flow through the armature, because, if the pressure is maintained constant at the terminals by the external source at 130 volts, there will be,

$$\frac{130 - 128 \text{ volts}}{\frac{1}{20} \text{ ohm}} = 40 \text{ amperes, by Ohm's law.}$$

There is thus a continual automatic adjustment between the amount of work which a motor has to mechanically perform, and the electrical current supplied to it.

110. In all except the smallest motors, the drop of pressure is a small fraction of the pressure supplied at the machine terminals. In a motor of one KW. capacity ($1\frac{34}{100}$ H. P.), the drop may amount to as much as 10 per cent., and in a motor of 500 KW. capacity, (670 H. P.), the drop may amount to as low as $1\frac{1}{2}$ per cent. of the terminal pressure. It is clear, therefore, that the C. E. M. F. of a motor is nearly equal to the pressure applied to the terminals, and, since this pressure, multiplied by the current, gives the intake of the machine, most of which is usefully yielded in mechanical output, the C. E. M. F. is an essential characteristic and necessary factor in all motors, and not a detriment to its operation, as might at first sight appear.

111. In considering the mechanical work that a motor is required to perform, two things must be taken into account; viz., first, the speed of rotation, and, second, the force exerted at the pulley, or the torque, and since (Sec. 9) work is always equal to the product of the force and the distance through which it moves, the work done by a motor is the product of the speed and the torque. If, as in Fig. 80, a weight of W, pounds be attached by a rope to a motor pulley P, whose circumference is exactly one foot, then every revolution of the pulley in the direction of the arrow will raise the weight one foot. The torque on the motor shaft is represented by the weight W, in pounds, which would have to be suspended from a pulley of one foot radius, in order to represent the same amount of pull as exists in any particular case. Thus, if the pulley P, on the motor shaft, had a diameter of three

feet, its radius would be one and one-half feet, and, if the weight lifted by the motor were $733\frac{4}{10}$ pounds, the torque would be $733\frac{4}{10}$ pounds $\times$ $1\frac{1}{2}$ feet $=$ 1,100 pounds-feet, since this would represent the corresponding weight upon a pulley of one foot in radius, or two feet in diameter, having the same amount of work to perform. At each revolution of the pulley, the weight will be lifted through a distance equal to its circumference, which will be $6\frac{28}{100}$ feet, so that the amount of work done in one revolution will be, $6\frac{28}{100}$ feet $\times$ $733\frac{4}{10}$ pounds $=$ 4,606 foot-pounds. If the motor makes 960 revolutions per minute, the work done in a minute will be 960 times as great, or $960 \times 4{,}606 = 4{,}421{,}760$ foot-pounds, and, since 33,000 foot-pounds per minute represents an activity of one H. P., the activity of the motor will be $\frac{4{,}421{,}760}{33{,}000} = 13\frac{4}{10}$ H. P. or 10 K.W.

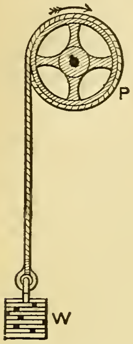


FIG. 80.
Motor pulley lifting a weight.

SYLLABUS.

In both a dynamo and motor there are E. M. F.'s and electrodynamic forces produced.

In the dynamo, the E. M. F. is direct to the current in the circuit, and the dynamic force counter to the mechanical force exerted.

In the motor, the dynamic force is direct and the E. M. F. counter to the current in the circuit.

In the generator, the pressure at the terminals is less than the C. E. M. F. by the amount of drop in the machine.

In the motor, the pressure at the terminals is greater than the E. M. F. by the amount of drop in the machine.

The product of the pressure at the terminals in volts and the current strength supplied to the motor in amperes, gives the intake of the motor in watts.

The torque of a motor, when expressed in pounds-feet, is the weight lifted, actually or virtually, at a pulley on its shaft one foot in radius.

The drop of pressure in a motor represents pressure lost in heating the armature wire, while the C. E. M. F. represents available pressure which multiplied by the current strength gives the total activity of the motor armature, and this, after deducting power lost in frictions, gives the available or useful activity of the motor, that is, its output.

Laboratory of Houston & Kennelly,
Philadelphia.

WEEKLY.

No. 23. NOVEMBER 17, 1894. Price, - 10 Cents. Subscription, $3.00.

Electrical Engineering Leaflets,

—BY—

Prof. E. J. Houston, Ph. D.
AND
A. E. Kennelly, F. R. A. S.

ELEMENTARY GRADE.

THE ELECTRIC MOTOR.

(CONTINUOUS CURRENT TYPE.)

112. The application of the electric motor to such industrial purposes as the running of elevators (see Fig. 81), or the operation of cranes and hoisting machinery generally, where a fixed load has to be moved at varying rates, represents a condition of constant torque and variable speed. When the motor is connected with constant-potential mains, the variation in speed is obtained in practice in two ways:

(*1.*) By inserting resistance in the armature circuit of a shunt-wound motor.

(*2.*) By commuting the fields so as to vary the M. M. F. of a series-wound motor.

113. The first method is diagrammatically illustrated in Fig. 82, where a resistance r_1, is inserted in the armature circuit r, of the motor whose magnets are operated direct from the mains, or in shunt to the armature. The current which drives the armature, in passing through the resistance, r_1, produces a drop in it of am-

Published by
THE ELECTRICAL ENGINEER,
203 Broadway, New York, N. Y.

[Entered as second-class matter at the New York, N. Y., Post Office, June 14, 1894.]

peres $\times$ ohms = volts. Thus, if the motor, in order to exert the torque required, has to take 50 amperes from constant-potential mains at 200 volts pressure, the rate at which it will run will depend upon the amount of C. E. M. F. the armature has to deliver. If no resistance existed in the armature or its circuit, the speed of the armature would be such as to produce 200 volts C. E. M. F.; and, in practice, if no external resistance were inserted, its speed would be sufficient to produce 200 volts, all but

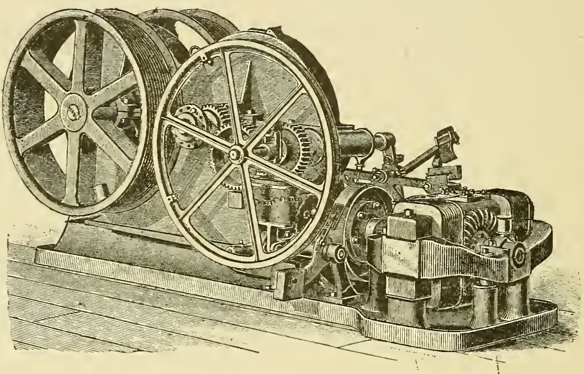


FIG. 81.—ELECTRIC ELEVATOR.

the drop produced by 10 amperes in the armature resistance.

If, however, the resistance r_1, inserted, together with the resistance of the armature, were just 4 ohms, then the drop produced by 50 amperes in this resistance would be 50 (amperes) $\times$ 4 (ohms) = 200 volts, and the armature would not be required to make up any C. E. M. F., so that it would exert its torque and would sustain the weight suspended from its pulley, but would not raise it. Now reducing the resistance below 4 ohms, the armature,

in rotation, if the torque be constant, will make up by its speed the C. E. M. F. equal to the drop reduced, and lift the weight at a proportionate speed. The work expended through four ohms of resistance, when the armature was at rest, was 200 (volts) $\times$ 50 (amperes) $=$ 10,000 watts $=$ 10 KW. $=$ $13\frac{4}{10}$ H. P., and all this power would be expended in heating the resistance. If, however, the resistance were entirely removed, so that the resistance of the armature was exceedingly small, the same amount of

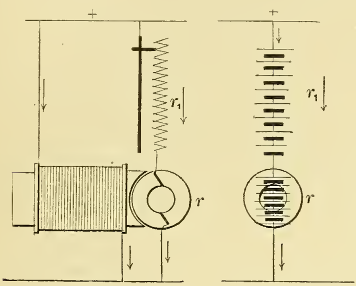
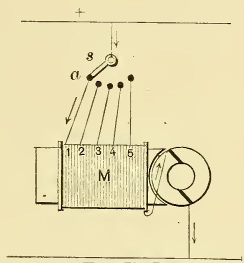


FIG. 82.
Regulation of Shunt-Wound Motor under constant Torque.



Elec. Engineer

FIG. 83.
Series Motor supplied from constant potential mains, and controlled by varying the number of field coils in its circuit.

power 200 (volts) $\times$ 50 (amperes) would be expended in raising the weight at the full speed of the motor. It is clear, therefore, that when resistance is inserted in the armature circuit of a shunt motor, the same amount of energy is taken from the mains, whether the motor armature be just turning over, or running at full speed; so that this method of attaining variable speed is a wasteful one. The figure also shows the voltaic analogue in the armature circuit of the case just presented. Here the E. M. F. between the mains is 200 volts, of which the

drop in the resistance r_1, makes up a part, and the drop in the armature, together with its C. E. M. F. due to rotation, makes up the balance.

114. Fig. 83 represents, diagrammatically, the case of controlling the speed of a series-wound motor by varying the M. M. F. of its field magnets. When a switch s, is connected with the button a, the current passing through the motor passes through all the coils, 1, 2, 3, 4, and 5, on the magnet M. Under these circumstances the M. M. F. of the magnet is at a maximum, and the flux passing through the armature will be also a maximum. The torque exerted by a motor for a given current strength will similarly be greatest, and the C. E. M. F. at a given speed of rotation will also be greatest. The current strength, which must pass through the motor in order to raise a weight supported by a pulley on the armature shaft is, therefore, reduced to a minimum, and the speed at which the motor has to run in order to produce the required C. E. M. F., which will let this current flow through the motor, is also a minimum. If it were possible indefinitely to increase the flux usefully passing through the armature by this means, it would be possible to make the motor run extremely slowly and yet take a very small amount of current, by producing nearly 200 volts at that low speed. By this means, when the work done in very slowly raising the weight was small, the amount of work taken from the mains electrically would be very small; and, on the contrary, when the motor was required to lift its weight rapidly, it would only be necessary to sufficiently reduce the M. M. F. of the field magnets, by cutting magnetizing coils out of circuit under the motion of the switch s, to

force the armature to accelerate in order to produce its necessary C. E. M. F. at the reduced flux, with a greater current from the mains, and doing work at a greater speed by more rapidly lifting the weight. In practice, however, the range over which this plan can be satisfactorily carried out is comparatively limited. The flux through the armature cannot be indefinitely increased, owing to the rapid rise in the reluctance of the magnets, when the flux density approaches saturation ; and, on the other hand, the M. M. F. cannot be too far diminished without dangerous sparking, owing to a preponderance of the armature flux over the field flux, with violent distortion of the magnetic circuit.

It is found possible, under favorable conditions, to double the speed of a series motor in this way, so that if the minimum speed be 500 revolutions per minute, the maximum speed will be, say, 1,000 revolutions per minute. In reality, however, the sections of the field coils, when inserted to reduce the speed, partly act by reason of the drop in them as additional resistances in the circuit. In practice, instead of merely cutting field coils in or out of circuit, it is customary to commute the coils also, that is, gradually to change them from series connection over to multiple connection. In the former case, with a uniform current strength, the M. M. F. is a maximum ; for the same current will pass through every coil, while in the latter case the M. M. F. will be a minimum, for each coil will now only receive a share of the current.

115 The condition of variable torque and constant speed is a condition usually met in driving machinery. For example, when a lathe is being driven by an electric motor, it is supposed to run at a uni-

form speed, but the power expended will vary under different circumstances, depending upon the character of the work. This condition is very fairly complied with by a shunt motor operated from constant-potential mains; for, neglecting the effect of drop in the armature resistance with increasing current strength, the C. E. M. F. of the motor has to remain constant, and the speed of the armature to produce that C. E. M. F. must therefore remain constant. The smaller the resistance of the armature, therefore, for a given full-load current strength, the less will be the drop in the armature at full load, and the less the variation in the C. E. M. F., which the armature has to produce in either case. A one KW. motor ($1\frac{34}{100}$ H. P.) that is, a motor capable of lifting one pound 44,240 feet per minute, will usually have about 5 per cent. drop in its armature at full load, so that the C. E. M. F., and the speed, will drop about 5 per cent. at full load, while a large motor, say of 200 KW., may only drop 2 per cent. Even this variation in speed can be compensated, by regulating the current passing through the shunt field by hand, and causing the M. M. F. to slightly diminish at increased load, thus reducing the armature flux, and increasing the speed at which the armature has to run to generate its C. E. M. F.

116. The condition of variable torque and variable speed is typically met with in the street-car motor, which has to exert a very different torque, according to the number of passengers in the car, and the gradient of the road, and has to also exert this torque at a greater or lesser speed in accordance with the requirements of the traffic. Here the same plan has to be adopted as already discussed in the case of constant torque and variable

speed ; that is, resistance has to be inserted in circuit with the armature, or the M. M. F. of the field magnets has to be varied. In practice both these methods are either separately or simultaneously employed. The motors are almost always series-wound, and their field coils frequently commutated, with the addition of external resistance, inserted when required.

117. As we have seen, the dynamo and motor are reversible machines. That is, they are machines which when driven by mechanical power will generate E. M. F., and when driven by current will generate mechanical power. The output, however, in the two cases is different, for, as a generator, the frictional losses of the machine are supplied from the engine, while, as a motor the frictional losses have to be supplied by a current, and, since the armature is only capable of maintaining the same full-load current in either case, the output as a motor will be reduced owing to the expenditure in friction. Thus, if a machine driven at 1,000 revolutions per minute, delivers 100 amperes at 100 volts terminal pressure, or an output of 10 KW., the frictions due to eddies, hysteresis, and journal bearings may amount to 2 KW. and the intake at the generator shaft will be 12 KW., supplied by the engine, but the armature can only sustain continuously 100 amperes at full load, without overheating or oversparking, when the machine is employed as a generator ; therefore, as a motor, its intake at the same speed will be practically limited to 100 amperes, and while its intake will be about 10 KW., its output will be reduced by the frictions to approximately 8 KW. The machine has, therefore, a greater output as a generator than as a motor. The larger the capacity of the machine, the less differ-

ence, however, usually appears between its performances in either case. For example, in small sizes, a 1 KW. generator may be practically rated as a 1 H. P. motor, and a 10 KW. generator as a 10 H. P. motor, but a 100 KW. generator would probably be about a 90 KW. motor.

Syllabus.

The variations in the speed of a motor under constant torque may be obtained either by varying the resistance in the armature circuit, or by varying the M. M. F. in the field magnet circuit.

A constant speed may be approximately obtained in a shunt motor, under variable torque, when supplied from constant potential mains. A series-wound motor will not automatically supply a constant speed under such conditions.

A dynamo electric machine has a greater output as a generator than as a motor.

Laboratory of Houston & Kennelly,
Philadelphia.

WEEKLY.

No. 24. NOVEMBER 24, 1894. Price, - 10 Cents. Subscription, $3.00.

Electrical Engineering Leaflets,

—BY—

Prof. E. J. Houston, Ph. D.

AND

A. E. Kennelly, F. R. A. S.

ELEMENTARY GRADE.

THE ELECTRIC MOTOR.

(CONTINUOUS CURRENT TYPE.)

218. An electric motor possesses many advantages over a steam engine. It is much more compact, lighter, simpler, more reliable, and requires less attention and repair. Moreover, it is more readily connected with its source of energy, requiring for this purpose only a pair of insulated conducting wires, instead of steam-piping, while the distance to which the wires can be carried is far greater than in the case of steam pipes.

219. The resistance of a motor armature is comparatively small, and is smaller as the capacity of the machine increases. Thus, a 10 KW. ($13\frac{4}{10}$ H. P.) shunt motor receiving, say 55 amperes at full load from constant potential mains at 220 volts pressure, would have a drop in the armature at full load of, say, five per cent. of the terminal pressure, or 11 volts; so that the resistance of its armature would be the volts divided by the amperes, or $\frac{11}{55} = \frac{1}{5}$ ohm. If such a motor, at rest, had its field magnets excited, and the armature then con-

Published by
THE ELECTRICAL ENGINEER,
203 Broadway, New York, N. Y.

[Entered as second-class matter at the New York, N. Y., Post Office, June 14, 1894.]

nected directly across the mains, the current which would flow through the armature, according to Ohm's law, would commence at $\frac{220 \text{ volts}}{\frac{1}{5} \text{ ohm}} = 1100$ amperes, or 22 times as much current as the motor is designed to carry at full load. Owing, however, to the inductance of the armature, (Sec. 160) a temporary C. E. M. F. is generated, by the sudden production of flux under the influence of the inrushing current, so that the current would not reach this large strength, and the armature would be rapidly brought up to speed under the powerful torque set up by the current. However, allowing for the utmost protective influence of the inductance in the armature, the first inrush of current would probably dangerously overload the armature, and might seriously damage it. Besides this, the effect would be to suddenly lower the pressure in the mains by the drop in them from so great a current. It is, therefore, necessary, when starting a motor from rest, to insert a resistance, called a *starting resistance*, in the armature circuit, so as to reduce the strength of the first flow of current, and then, as the motor comes up to speed, gradually to cut out this starting resistance, until the motor has attained its full rate. The C. E. M. F. of the armature then regulates the amount of current passing through it, according to the load on the machine. Thus, in the case of the shunt machine before referred to, the starting resistance should not be less than $3\frac{4}{5}$ ohms, since the total resistance in the armature circuit would then be $3\frac{4}{5}$, plus $\frac{1}{5}$ in the armature $= 4$ ohms, and the current strength, by Ohm's law, could not exceed $\frac{220}{4} = 55$ amperes, the full-load current. When the motor reached

half speed, its C. E. M. F. would be about 104 volts, making a current $\frac{220 - 104}{4} = \frac{116}{4} = 29$ amperes, and the starting resistance could be reduced to about two ohms, without exceeding the full-load current through the armature.

220. The starting of a series-wound motor from a state of rest, is less dangerous to the armature than the starting of a shunt motor, since the resistance and inductance of the field coils in the armature circuit

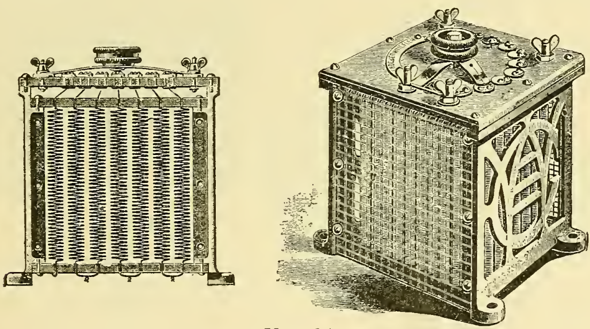


FIG. 84.

Starting Resistance Box for Small Stationary Motors.

impede the first rush of current. Still, even in such a machine, the tendency at starting is to produce an excessive current which, however, is soon stopped by the C. E. M. F. of rotation. A form of starting box frequently employed with small stationary motors is shown in Fig. 84. In street car motors, which are practically always series-wound, a rheostat is frequently employed, such as shown in Fig. 85. Here a large number of sheet metal stampings are inserted in a semi-circular groove, in the path of

the scraping contact D. Such a resistance may have a maximum value of about 20 ohms, so that a current passing through it direct from the trolley to ground, at 500 volts pressure, would not exceed 25 amperes, even if the car motors were entirely short-circuited.

221. In order to reverse the direction of rotation of a motor, it is necessary to reverse the direction of the M. M. F. in either the field magnets or the armature; i. e., to reverse the current in either field or armature.

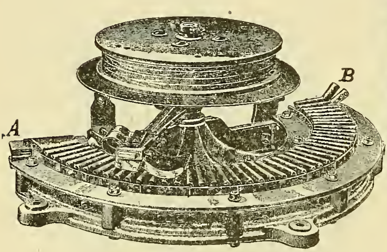


FIG. 85.
Street Car Rheostat.

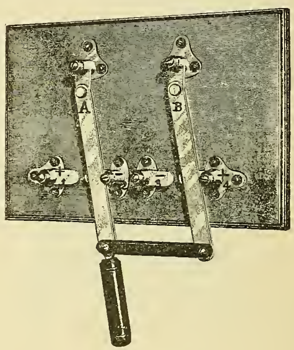


FIG. 86.
Reversing Switch.

The armature terminals are usually reversed by means of a suitably constructed switch, such, for example, as that shown in Fig. 86. When the handle is turned to the right, as represented, the armature, whose brushes are connected to the strips A and B, has the strip B connected to the positive terminal 4, and the strip A connected to the negative terminal 2. On throwing over the handle to the left, however, the strip B is transferred to the negative terminal, and the strip A to the positive terminal,

thus reversing the direction of current through the armature.

222. There is considerable danger in suddenly reversing the current through a rotating armature, owing to the excessive rush of current which may take place; for, when the switch is thrown, the armature, still rotating by its momentum in the original direction, is developing an E. M. F. which is now no longer counter to the direction of the driving current, but in its direction, and therefore tending to increase its amount instead of opposing it. Thus, the shunt motor previously considered, when generating 209 volts C. E. M. F. at 1000 revolutions per minute, would, if suddenly reversed, tend to set up a current in the armature of the strength $\frac{220 + 209 \text{ volts}}{\frac{1}{5} \text{ ohm}} = \frac{429 \text{ volts}}{\frac{1}{5} \text{ ohm}} = 2145$ amperes, or about 40 times the full-load current. Here again, the inductance of the armature would assist in checking the first inrush of current, but there would still tend to be a very great excess, prejudicial to the source of power supplying the mains, and dangerous to the armature. For this reason, when a motor has to be frequently reversed in the direction of its rotation, it is usually series-wound, so that the resistance and inductance of the field coils may tend to check the excessive rush of current.

Reversing the direction of current supplied to the main motor terminals, will not, unless the motor is separately excited, reverse the direction of rotation, because the M. M. F. of both field and armature are reversed.

223. When a locomotor is exposed to mud or dust, it is necessary to encase its revolving parts in a mud and dust-proof metal covering. The pressure at which

such a machine operates, is usually not more than 220 volts. In order to prevent any severe shock from being obtained by accidental contacts in the damp underworks of a mine, all the metallic parts connected with this pressure are carefully protected from contact. A form

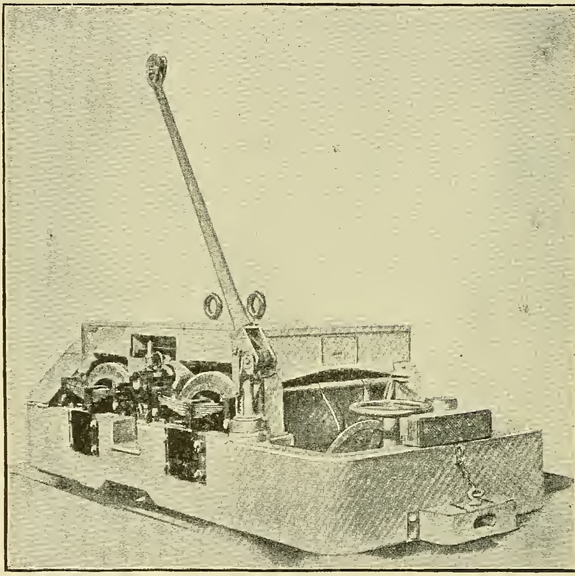


Fig. 87.
Mining Locomotor.

of mining locomotor, capable of exerting 3000 lbs. pull at the draw bar, is represented in Fig. 87.

224. Owing to the difficulty hitherto experienced in maintaining the necessary degree of insulation and freedom from sparking at the commutator, continuous-

current motors are rarely constructed for more than 1000 volts pressure, but they have been operated at as high a pressure as 5000 volts. Occasionally, it is found convenient to couple 500 volt motors in series, so as to make a total pressure of, say, 2000 volts, between extreme terminals. In such cases, it is necessary that the motors should be mechanically coupled in such a manner that their speeds must be alike, and also that the insulation of their parts should be very carefully maintained.

225. Small motors are sometimes operated in series-arc light circuits. Such motors are always series-wound and are so arranged that their speeds cannot become excessive, either by a definite load or by some form of governing.

Care should be taken not to come in contact with the wires or frame of a motor in a series arc circuit, since the pressure in the circuit may be very high, and an accidental contact, when standing on a metallic or wet floor, might be fatal.

The brushes of any dynamo-electric machine, whether a generator or motor, should never be lifted while the machine is in operation; or, if two brushes are working side by side, never more than one should be lifted at any time, since the breaking of the armature circuit may produce a dangerously high E. M. F. due to self induction, which might give a powerful shock or pierce the armature insulation, resulting in permanent damage to the armature.

SYLLABUS.

A starting resistance should always be introduced into the armature circuit of a shunt motor, either for starting it or for reversing it.

In order to reverse the direction of rotation of a motor, the M. M. F. of either its field magnets or its armature must be reversed.

The direction of rotation of any motor is not reversed by reversing the direction of current in the leads which supply it, unless the motor is separately excited.

The circuit of a motor, while running, should never be suddenly broken by the lifting of its brushes, owing to the danger of producing a high E. M. F. of self induction in armatures or magnets.

Laboratory of Houston & Kennelly,
Philadelphia.

WEEKLY.

No. 25. DECEMBER 1, 1894. Price, - 10 Cents. Subscription, $3.00.

Electrical Engineering Leaflets,

—BY—

Prof. E. J. Houston, Ph. D.

AND

A. E. Kennelly, F. R. A. S.

ELEMENTARY GRADE.

ELECTRIC HEATING.

---

226. We have already enumerated the various classes of effects produced by the passage of an electric current through a conductor. Some of these effects, as, for example, the magnetic and heating effects, are produced in all cases; that is, whether they are desired or not. By suitably proportioning the resistance and dimensions of a circuit to the current strength it has to carry, the heating effects can be rendered more or less marked as may be desired. In the case of commercial circuits, conveying currents for light or power, the object is to produce in the conducting wires as little heat as possible, and to produce it under circumstances which will prevent the overheating of the conductors. The object in electrical heaters is to produce as great a safe increase of temperature, as possible, with the minimum amount of electrical energy.

227. When an electric current is sent through a conductor, the amount of energy liberated in the conductor as heat, will be the square of the current

Published by
THE ELECTRICAL ENGINEER,
203 Broadway, New York, N. Y.

[Entered as second-class matter at the New York, N. Y., Post Office, June 14, 1894.]

strength in amperes, multiplied by the resistance of the conductor in ohms. Thus, if a current of five amperes be made to pass through a resistance of two ohms, the energy expended in the wire will be $5 \times 5 \times 2 = 50$ watts (Sec. 171). This amount of energy will be practically the same, whether the current be alternating or continuous, so long as the effective current strength, as indicated by a properly calibrated ammeter, remains at five amperes.

228. The rise of temperature in a conductor, caused by the passage of an electric current, depends upon a variety of circumstances; namely, the amount of heat liberated per second in the wire, on the nature of the surrounding medium, and on the nature and temperature of the bodies in its neighborhood. The energy liberated in a given length of the conductor depends upon its resistance, and upon the current strength, while the facility with which the heat so developed can escape depends upon the surface of the conductor; i.e, upon its diameter and length, and upon the conditions of its surface.

229. The rise of temperature produced in a conducting circuit by the passage of an electric current through it, may be considered either from the standpoint of economy, or from that of safety. Economical distribution of electrical energy requires that the total expense of transmission, including that of the energy expended in the conductor, together with the cost of the conductors, should be a minimum. In order to comply with these conditions, the wires may sometimes have to be very small. On the other hand, such wires might be

so overheated by the currents they carry as to render them dangerous to run through buildings. It is, therefore, necessary to determine the safe carrying capacity of any given size of wire. It is sometimes specified that a safe current density for a copper wire is 1,000 amperes per square inch in area of cross-section, so that a wire having a cross-sectional area of $\frac{1}{10}$th square inch would be permitted to carry 100 amperes. Such a rule, however, while allowing a wide margin of safety for small wires, is unsafe for very large wires.

A wire which can be grasped in the bare hand without any uncomfortable heating effect may be regarded as at a safe temperature. The wire on the surface of a dynamo field magnet is not dangerously overheated when the hand can be borne on its surface. A wire which can be so kept in the hand without pain has a temperature of about 122° F. If the temperature of surrounding bodies be, say, 68° F., such a wire can, therefore, safely have a temperature elevation of 54° F., but such a wire would be brought almost to the boiling water temperature by an accidental overload of 50 per cent.

The rule for the safe carrying capacity of wires, adopted by the various fire insurance authorities, requires, however, a greater margin of safety, since their prescribed limit corresponds to a full load temperature elevation of about 18° F. Such rules admit of accidental overloads of 100 per cent. without raising the temperature of the wire over 150° F.

The following is a table showing the size of copper wire in A. W. G. or B. & S. gauge which will be raised 36° F. in temperature by the current strengths shown.

Amperes	Covered Wire in Wooden Moulding.	Bare Wire Suspended Horizontally in Still Air Within Doors.		Bare Wire Suspended Horizontally in Calm Weather Out of Doors.	
		Bright	Blackened.	Bright.	Blackened.
	A. W. G.	A. W. G.	A. W. G.	A. W. G.	A. W. G.
5	24	26	27	29	30
10	19	20	21	23	24
15	16	17	17	20	20
20	13	14	15	17	18
25	11	12	13	16	16
30	10	11	12	14	15
35	9	10	11	13	13
40	8	9	10	12	12
45	7	8	9	11	12
50	6	7	8	10	11
60	5	5	6	9	10
70	4	4	5	8	9
80	3	3	4	7	8
90	2	2	3	7	7
100	2	2	3	6	6
125	1	0	1	5	5
150	0	00	0	3	4
175	00	000	00	2	3
200	000	0000	000	2	2
250	0000	......	......	0	0
300	......	......	......	00	00
400	......	......	......	000	000

230. If a house circuit, intended for the supply of fifty incandescent lamps, be connected with constant potential mains of 250 volts pressure, the full-load current supplied by these wires will be about 12.5 amperes. If, however, an accidental short-circuit takes place at any lamp, the resistance of the circuit within the house is enormously diminished, and, by Ohm's law, a very great strength of current will immediately flow through the house wires, which would dangerously overheat or, perhaps, even melt them. Devices called safety fuses are, therefore, introduced into the circuit, which fuse as soon as the current strength becomes danger-

ously great, and thus automatically open the circuit of the mains. Safety fuses are usually made of an alloy of lead and tin; they have a high resistance and a low melting point.

231. When a fuse is melted by a sudden excess of current the metal is sometimes volatilized in the interior of the fuse before the surface layers are melted, in which case the fuses are disrupted with explosive violence. Care should therefore be taken not to leave inflammable material in proximity to a fuse wire,

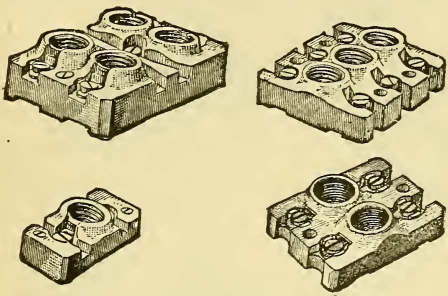


Fig. 88.
Fuse Blocks.

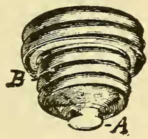


Fig. 89.
Fuse Plug.

since molten particles of the fuse may be driven to a distance of several feet. As a further protection against fire from this cause, the fuse wire is generally enclosed in a porcelain block, called a *fuse block*. These blocks are of various forms, some of which are shown in Fig. 88. The lead wires are secured beneath the screw binding posts, and the current has to pass through the block receptacle containing the fuse wire and illustrated in Fig. 89. By screwing this plug into its receptacle in the fuse block, the current enters it at one terminal, say A, at the apex of the glass plug,

passes through a short length of fuse wire in the interior, and then passes to the brass screw thread B, which makes contact with a similar brass thread in the receptacle. Such fuse plugs are commonly employed in house wiring circuits, where only a few amperes are carried. For more powerful currents, *fuse strips* are generally employed, such as shown in Fig. 90. In order to secure good terminal contact they are tipped with copper lugs. The position of such a fuse link in its mica covered block, is shown in Fig. 91. A simple form of fuse holder for a still larger strip is shown in Fig. 92.

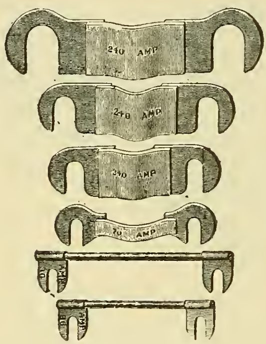


FIG. 90.
Copper Tipped Fuses.

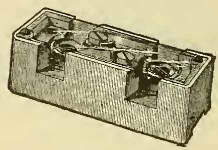


FIG. 91.
Fuse Strip Block.

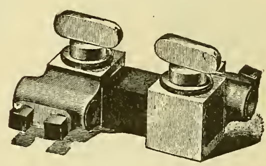


FIG. 92.
Fuse Holder.

232. The heating effects of electric currents are commercially employed in a variety of electric furnaces for the smelting of refractory ores; for the melting and refining of metals, and for artificial heating and cooking. The ease with which electric heat can be turned on or off, taken in connection with its freedom from dirt and smoke, are bringing electric heaters into favor. An electric heater consists essentially of a wire

resistance, surrounded by a refractory material, which is also a non-conductor of electricity, placed in connection

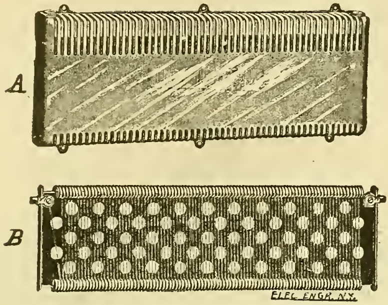


Fig. 93.
Street Car Heater.

with the surface to be heated. Fig. 93 represents a form of heater for electric cars, arranged to be placed beneath the seat as shown at A. The interior of the instrument is shown at B, and consists of a wire wrapped many times around a large frame.

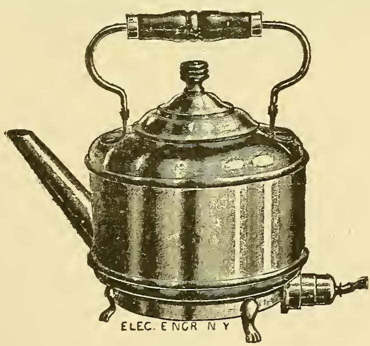


Fig. 94.
Electrically Heated Kettle.

An electrically heated tea kettle is shown in Fig. 94. Here the heating coil, suitably protected from contact

with the water, is placed at the base of the kettle and connected by the plug with a pressure of 50 or 110 volts, alternating or continuous.

An electrically heated oven is shown in Fig. 95. The advantage of being able to control the heat is indicated by the use of the thermometer, so that the cooking can be conducted on strictly scientific principles.

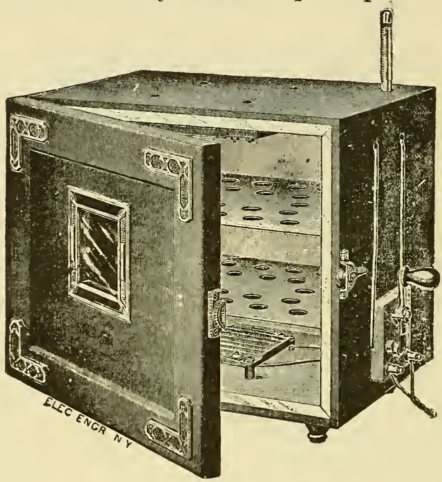


FIG. 95.
Electric Oven. Size, 18 in. x 14 in. x 12 in.

SYLLABUS.

An electric current passing through a conductor heats it, and the heat produced varies with the resistance of the conductor and with the square of the current strength.

A wire has a safe temperature, when it can be held in the hand without pain.

The same rule applies to the temperature of dynamo field magnets.

Laboratory of Houston & Kennelly,
Philadelphia.

WEEKLY.

No. 26. DECEMBER 8, 1894. Price, - 10 Cents. Subscription, $3.00.

Electrical Engineering Leaflets,

—BY—

Prof. E. J. Houston, Ph. D.

AND

A. E. Kennelly, F. R. A. S.

ELEMENTARY GRADE.

INCANDESCENT LIGHTING.

233. In the incandescent electric lamp, the heating effect of the electric current is utilized, by raising a substance that is difficult to fuse, to a high temperature, under circumstances in which it cannot burn or rapidly disintegrate. The substance employed for this purpose is carbon, generally in the shape of a slender thread called a *filament*. In order to protect the carbon from burning, the filament is placed inside a glass globe from which, as nearly as possible, all the air has been removed. The current is led into the lamp by two *leading-in wires* formed of copper, except where they pass through, and are fused into, the glass walls at the base of the glass globe, where they are formed of platinum. The ends of the leading-in wires are connected to the metal parts of the base, which are insulated from one another by suitable insulating material. The insertion of the lamp base into the *lamp socket* mechanically connects the filament with

Published by
THE ELECTRICAL ENGINEER,
203 Broadway, New York, N. Y.

[Entered as second-class matter at the New York, N. Y., Post Office, June 14, 1894.]

the supply mains. The different portions of the incandescent lamp are shown in Fig. 96. The carbon filament

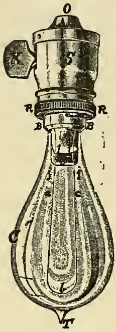


Fig. 96. Incandescent Lamp.

a b c, is jointed at *j j*, to two platinum wires fused through the glass support s, and connected at their free ends with copper leading-in wires *i i*, respectively connected to the terminals of the base. The lamp base is generally screwed into the socket s, and the circuit of the lamp is closed or opened by means of a key K.

234. Various processes have been adopted for the preparation of the filament. They all consist essentially in suitably subjecting some carbonizable material, generally of vegetable origin, such, for example, as bamboo fibre, to the action of prolonged heat out of contact with air. The effect of carbonization is to drive off everything from the material but the carbon, which is left as an electrically conducting skeleton thread, or filament.

The carbonizing process is generally effected as follows; viz., the filament is placed in a crucible and surrounded by powdered charcoal, so as to exclude air, and then heated for several hours in a furnace. When removed from the furnace and thoroughly cooled, the filament is then connected to the platinum leading-in wires, which have previously been soldered to the copper wires *l l*, and sealed into the support s, by fusing the glass around them. Platinum is used for sealing into the glass, because, when heated or cooled, platinum expands or contracts nearly the same as glass, and, therefore, does not break the glass on sudden changes of temperature. Platinum is the only metal that will do this, and at the

same time possesses the additional requisite of having its melting point so high that it will stand the fusion of the glass around it.

235. The mounted filament is now usually subjected to a process called the *flashing process*, which, while no longer necessary, as formerly, for the purpose of rendering the filament electrically homogeneous, is found to render an ordinary filament more durable and less readily disintegrated. This process is carried on essentially as follows. The mounted filament is heated to low incandescence while surrounded by a hydrocarbon vapor, such as rhigolene, cymogene or some other coal oil distillation product. When a heated surface is brought into contact with a hydrocarbon vapor, the vapor is decomposed and the carbon is deposited on the hot surface in a solid, electrically conducting state. When, now, the filament is heated by the passage of the current through it, good electrically conducting carbon is deposited in its pores and over its surface. Should the filament fail to be uniform in resistance throughout its length, the higher resistance portions are first brought to incandescence, while the lower resistance portions are still cold, and the filament does not glow uniformly. By the flashing process, however, the points of high resistance, which first begin to glow, receive a coating of deposited carbon, so that their resistance becomes reduced, and, if the current strength is gradually increased, the successive deposits of carbon will soon render the filament uniformly conducting, when it will glow with equal brilliancy throughout its entire length.

236. The flashed filament is now introduced into the glass chamber or bulb C, and the neck of this bulb is fused around the glass stem S, thus hermetically sealing the lower part of the chamber.

The lamp is then connected to the vacuum pump by means of a small glass tube, attached to an opening left at T, before the final sealing of the lamp, and a high vacuum is obtained. During the last stages of exhaustion a current of sufficient strength to bring the filament to full incandescence is sent through the lamp, thus heating the filament and the lamp chamber and driving off the air, which has either been absorbed by the filament, or condensed on the inside walls of the glass bulb. If this is not done before the lamp is sealed, its lifetime will be very greatly reduced, since at its first employment the lamp would liberate these gases, spoil the vacuum and rapidly destroy the filament. As soon as a sufficiently high vacuum is obtained, the lamp is hermetically sealed at T, by the fusion of the glass and is thus released from the pump. The leading in wires are now soldered to the conducting portions of the lamp base, and, after filling this with plaster of Paris and testing, the lamp is complete and ready for use.

237. The illuminating power of a lamp is measured in standard candles. In America and Great Britain, the *standard candle* is a candle of definite composition, burning at a definite rate, under suitable conditions. The ordinary incandescent lamps, in the United States, are made, under normal conditions, to give 16 candles. A 16 candle-power lamp, intended for operation, at, say, a steady pressure of 115 volts, will show a marked increase in its candle-power if the pressure is

but slightly increased, for the reason that an increased current makes the temperature of the filament higher and the brilliancy of the light increases rapidly with the temperature. Assuming a new lamp to be in good condition, if it is dull when first connected with its supply mains, it is evident that the pressure at the lamp terminals is too low, as a voltmeter connected with such mains should show.

A lamp gives the same candle power at the same pressure of alternating or continuous current. Thus if a lamp gives 16 candles and takes half an ampere at 115 volts pressure on a continuous current circuit, it will give 16 candles and take the same amount of current on an alternating current circuit at 115 volts pressure.

238. After a lamp has been operated for some time, the filament disintegrates, or wears away, and the disintegrated carbon is deposited on the glass bulb, thus blackening it. The consequent decrease so produced in the diameter of the filament, causes an increase in its resistance and lessens the amount of current which passes through it from the constant potential mains. Consequently, it not only gives a smaller amount of light, but less of this light escapes through the darkened globe, and a point is at length reached at which, if the filament does not break, the lamp is no longer fit for use as an efficient illuminant.

239. The value of an incandescent lamp, from an engineering point of view, is dependent upon the number of candles it will give per watt or per horsepower. The *efficiency* of a lamp may be defined as the number of candles it will give per watt, or,

$$\text{efficiency} = \frac{\text{The number of candles yielded by the lamp.}}{\text{The number of watts absorbed by the lamp.}}$$

The efficiency of a lamp depends upon the quality of carbon of which its filament is constructed; but, taking lamps having the same quality of carbon, the higher their efficiency, the higher must be their temperature and their brilliancy. It is possible to obtain lamps which will give one candle for every watt that they consume, representing 746 candles per electrical horse-power or 50 candles from a fifty watt lamp. Such a lamp, however, would be extremely brilliant and would have a very short life, rapidly disintegrating.

The highest efficiency at which lamps are ordinarily operated is $\frac{1}{3}$ candle per watt, and this necessitates a temperature and brilliancy at which their life will generally not average more than 800 hours. If, however, the lamp have its filament increased in size, so as to give the same number of candles at a lower temperature and brilliancy, and so that it operates at an efficiency of $\frac{1}{4}$ candle per watt, the life of the lamp will probably be six times as great, or average about 4800 hours. When, therefore, it is desired to obtain a maximum amount of light from a given amount of electrical energy, high efficiency lamps are necessary, but where, on the contrary, a long life is desired, and where the cost of the electrical energy consumed is not the leading consideration, lower efficiency lamps should be employed. The high efficiency lamps will be shorter lived, especially if their pressure is not maintained uniform; for, if a high efficiency lamp operating at 115 volts, and already at a high temperature, is accidentally supplied with 118 volts pressure, the increase in brilliancy and temperature so produced will be very great, but the depreciation of the filament will be equally marked, while the same accidental rise in pres-

sure on a low efficiency lamp, of the same initial candle power, would not increase its temperature or brilliancy at nearly so dangerous a rate. High efficiency lamps should, therefore, only be employed in electric lighting systems where the closest attention is always given to the regulation of pressure, as, for example, in systems operated from central stations. On the contrary, where the pressure is less closely watched, lower efficiency lamps are more economical, owing to the lesser damage from accidental excess of pressure.

Owing to the diminution with age of the light yielded by a lamp, its efficiency steadily diminishes, so that a lamp which, when new, has an efficiency of $\frac{1}{3}$ candle per watt, may, after 1,000 hours of burning, only possess an efficiency of $\frac{1}{6}$ candle per watt.

240. The transparency of the lamp globe, when affected by deposit inside the chamber, cannot be remedied, but the opacity due to the settling of dust or soot on the outside, which is sure to occur in dusty or smoky atmospheres, can be entirely removed by cleaning them.

Incandescent lamps are made for pressures varying from 200 to 220 volts, 120 to 100 volts, and from 55 to 50 volts. For special purposes they are made for pressures below ten volts. Miniature lamps are sometimes made for pressures as low as two volts, and are usually operated by voltaic batteries.

The efficiency of very small lamps is however usually low, say $\frac{1}{8}$ candle per watt.

Syllabus.

An incandescent lamp consists essentially of an electrically heated carbon filament preserved from contact with the air by being enclosed in a vacuum within a glass vessel.

The illuminating power of a lamp is measured in candles.

The efficiency of new lamps in ordinary use, varies from $\frac{1}{4}$ to $\frac{1}{3}$ candle per watt.

The efficiency of a lamp is equal to the number of candles yielded by the lamp divided by the number of watts absorbed by the lamp.

High efficiency lamps require careful regulation of pressure in order to ensure their durability.

Low efficiency lamps call for less careful regulation of pressure.

The higher the temperature and brilliancy of a lamp, the higher its efficiency, independently of the number of candles it gives.

Laboratory of Houston & Kennelly,
Philadelphia.

WEEKLY.

No. 27. DECEMBER 15, 1894. Price, - 10 Cents. Subscription, $3.00.

Electrical Engineering Leaflets,

—BY—

Prof. E. J. Houston, Ph. D.
AND
A. E. Kennelly, F. R. A. S.

ELEMENTARY GRADE.

INCANDESCENT LIGHTING.

241. The amount of light received by any body per square inch, or per square centimetre, of its surface, is called the *illumination* of the body. The illumination received by an illuminated body is greater, the greater the quantity of light emitted by the source, and the nearer it is to the source. If a book be held before a candle at a distance of, say, one foot, the amount of illumination received by the book from the candle is called a *candle-foot;* if the book be moved to a distance of two feet from the candle the illumination will be only one quarter of a candle-foot. Generally, where the source of light can be regarded as a point, the intensity of illumination received by any area will diminish with the square of the distance from the luminous source; i.e., at nine feet from the candle the illumination will be 81 times less than at one foot, or $\frac{1}{81}$ candle-foot.

242. An illumination of one candle-foot upon a printed page, as of a book, is sufficient for easy reading. In the actual illumination of buildings by in-

Published by
THE ELECTRICAL ENGINEER,
203 Broadway, New York, N. Y.

[Entered as second-class matter at the New York, N. Y., Post Office, June 14, 1894.]

candescent lighting, it becomes important to determine the amount of illumination required for different kinds of work. In an ordinary room, where the character of the walls and the ceilings is such that a considerable amount of light is reflected and diffused from them, the illumination produced upon a table or upon the pages of a book, is always greater than that which would be deduced from the mere application of the preceding rule, relating to the decrease in the intensity of the light with the distance from the luminous sources. It is found in practice that well lighted rooms, adapted for reading, will generally be well served by one 16 C. P. incandescent lamp to 50 square feet of floor surface, while for an ordinarily well lighted room, not intended especially for reading, one 16 C. P. lamp to every 100 square feet of floor surface is usually regarded as sufficient lighting.

243. An incandescent electric lamp possesses numerous advantages as an artificial illuminant over either gas or coal-oil; namely,

(*1.*) It is capable of affording a uniform character of illumination free from sharply marked regions of light and shadow since the light can be readily divided.

(*2.*) It is capable of affording an agreeable and steady illumination, entirely free from disagreeable flickering.

(*3.*) It is free from noxious fumes and produces less heating than would an equal amount of gas or oil light.

One 16 C. P. gas burner vitiates the air to about the same extent as 12 adult persons. One 16 C. P. incandescent lamp does not vitiate any air, and gives only $\frac{1}{8}$ of the amount of heat produced by a 16 C. P. gas jet.

(*4.*) It is much safer than a naked gas flame, since it is placed in a closed chamber and does not require to be

lighted by matches. In the event of a fracture of the glass chamber, the globe is collapsed and not exploded.

244. Various devices have been employed at different times since the earliest stages of the art of incandescent lighting, to produce a lamp, the illuminating power of which can be varied by a process similar to the turning down of a gas burner. Such devices consist either in the introduction of a resistance into the circuit of the lamp, or the introduction of an additional filament, contained in the lamp chamber, into the circuit. Such a lamp is called a *multiple-filament lamp*. Both methods are open to the grave objection that not only the amount, but also the character, of the light, is altered, since the current through the filament is reduced in strength, thereby reducing both its efficiency and its temperature, so that the lamp gives a light of duller color. An ideal device would be one in which the same temperature and luminous efficiency of filament could be preserved, with a reduction in the length or surface of filament in operation, so as to emit a correspondingly reduced quantity of light.

245. Incandescent lamps are usually connected to the supply mains in multiple. In some cases, however, they are operated in series, usually for street lighting. In other cases they are introduced into arc circuits. All series-incandescent lamps have coarser filaments than multiple-connected lamps and are intended to carry a stronger current. Thus the arc circuit incandescent lamps have to carry a current of about 10 amperes, so that a 16 candle-power lamp may have a working pressure at its terminals of about six volts.

In multiple-connected lamps the fracture of one lamp does not affect the continuity of the main circuit. In a series-connected system, however, the fracture of a single filament must necessarily interrupt the continuity of the entire circuit, unless some device is introduced into the circuit for automatically closing the circuit and cutting out the deficient lamp. Various methods have been adopted for accomplishing this, one of which, called the *film cut-out* is shown in connection with Fig. 97, which represents a series incandescent lamp with a film cut-out.

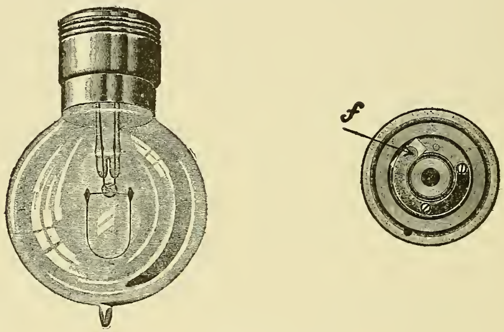


Fig. 97.
Series Incandescent Lamp with Film Cut-Out.

As shown, the film cut-out consists of a thin piece of paper inserted at *f*, between two strips of metal connected with the terminals of the lamp. Should the filament break, the pressure, instead of being, say, six volts, would tend to rise to the full E. M. F. in the circuit, say, 1000 volts, and this high pressure would be sufficient to produce a disruptive spark discharge through the paper, arcing through it and fusing the two strips into contact, thus short-circuiting the lamp.

246. In series connected lamps the drop in the connecting wires of the circuit has no prejudical effect upon the system, except in so far as it entails loss of energy and an increase in pressure at dynamo terminals; for every lamp must carry its full current strength. But in a multiple connected incandescent circuit, the drop in the supply mains, unless everywhere uniform between the source of supply and the lamps, is very prejudicial to the uniformity of their lighting, and to their life. If some lamps, say of 110 volts normal pressure, in a multiple connected system, have a drop of 10 volts in the mains supplying them, while others are so favorably situated, that is, so near to the dynamo or to the source of supply, that there is practically no drop in their circuit, it is evident that if the distant lamps are operated at 110 volts, the nearest lamps must be operated at 120 volts, entailing a very high temperature, efficiency, and illumination, but with a far too rapid consumption of the carbon filament by disintegration and with a great reduction of life. It becomes, therefore, a matter of great importance, in planning systems of multiple incandescent lighting, to prevent the drop in pressure at any parts of the systems differing by more than a certain small range. Thus, in a large building operated from a generator in the basement on the two-wire system, with lamps of, say, 110 volts, the drop is usually specified to be not greater than five per cent. of the generator pressure, so that when all the lamps are operated together, the average pressure in the system being 110 volts, that at the lamps nearest to the generator will be $112\frac{8}{10}$ volts and at the most distant lamp $107\frac{2}{10}$ volts. In a small building of, perhaps, but fifty lights, the drop

permitted with the wiring at full load, would usually not exceed 2 per cent. of the generator or supply pressure.

247. The drop in any wire expressed in volts being equal to the amperes it carries multiplied by its resistance in ohms, can be reduced to the necessary limit by sufficiently diminishing the resistance of the wires, that is, by sufficiently increasing their diameter, the current being determined by the number of lamps. For a given number of lamps to be supplied with a given distribution in a building, the amount of copper which must be employed to limit the drop to any determined amount will be inversely proportional to the square of the pressure. Thus, if 50 volt 16 candle-power lamps are employed, they will each take, say, one ampere, and the drop in the supply wires, having one ohm resistance, would be one volt, which would be about two per cent. of the supply pressure. If now, the lamps be changed for 100 volt lamps of the same candle-power and efficiency, each lamp will now take only half an ampere, and the drop produced by this half ampere in the same wires of one ohm resistance will only be half a volt, which is $\frac{1}{2}$ of one per cent. of the pressure, a reduction in drop percentage, of four times, for a doubled increase in the pressure.

248. The three-wire system, which enables the pressure in a building to be double that required for any single lamp, would, therefore, save 75 per cent. of the copper in wiring for the same amount of drop, but, allowing for the additional or third wire, it actually saves about 60 per cent.

The difficulty of equalizing the drop with supply mains, increases with the area covered by the mains.

Thus, in systems of low-tension incandescent lighting employed in large cities, the difficulty of maintaining a fair equality of pressure would require prohibitively large mains of copper, if *feeders* were not adopted, that is to say if special conductors were not carried from the generator bus-bars to the mains, without being directly connected to any lamps, so that the feeders supply the mains and the mains supply the lamps. By these means the drop in pressure in the feeders, which may be of

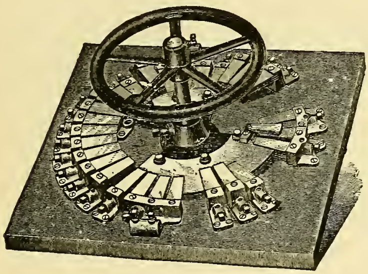


FIG. 98.
Feeder Equalizer Switch.

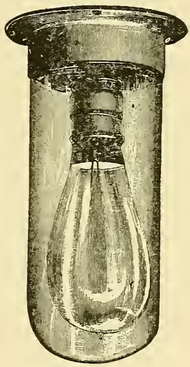


FIG. 99.
Steam Tight Lamp Cover.

comparatively small size, may be very considerable, say 10 to 20 per cent, and yet the pressure of the net work of mains, supplied by the feeders may be very nearly uniform. Where the drop in the feeders is not uniform, special rheostats, called *feeder equalizers*, are sometimes introduced into their circuits, thus artificially reducing them to the same electrical length. Fig. 98, represents a form of feeder equalizer switch. By the rotation of the handle, resistance coils, connected with the contacts,

are thrown, either in parallel or in series, into or out of the circuit of the feeders.

Where lamps have to be connected in situations exposed to steam or other vapor, an expedient is sometimes adopted of surrounding the lamp chamber by a glass cover, which prevents moisture from coming into contact with the lamp. Such a cover is represented in Fig. 99.

Syllabus.

The illumination of a body is the amount of light received by its surface per square inch or per square centimetre.

Series incandescent lamps are employed in some street lighting systems and also in some series arc systems. Such lamps have to be provided with a device to cut them out of circuit when their filament breaks.

Laboratory of Houston & Kennelly,
Philadelphia.

WEEKLY.

No. 28. DECEMBER 22, 1894. Price, - 10 Cents. Subscription, $3.00.

Electrical Engineering Leaflets,

—BY—

Prof. E. J. Houston, Ph. D.
AND
A. E. Kennelly, F. R. A. S.

ELEMENTARY GRADE.

ARC LIGHTING.

249. When a sufficiently powerful current is sent through two carbon pencils, which are first in contact and then gradually separated a short distance, say $\frac{1}{8}$ of an inch, a brilliant arc of flame, called the *voltaic arc*, is formed between them. The voltaic arc consists of highly heated carbon vapor. The high temperature, caused by the passage of the current through the high resistance at the loose contact, vaporizes the carbon, so that, when the carbons are separated a short distance, the circuit between them is not broken, but is continued through the column of vapor. The volatilization occurs almost entirely at the free end of the positive carbon, where the current passes into the arc. This volatilization has the effect of hollowing out the end of the positive carbon in the form of a minute *cup* or *crater*. The negative carbon, although at a very high temperature is, nevertheless, sufficiently cool to permit part of the carbon vapor to be condensed on its surface, where it collects as a minute hillock

Published by
THE ELECTRICAL ENGINEER,
203 Broadway, New York, N. Y.

[Entered as second-class matter at the New York, N. Y., Post Office, June 14, 1894.]

or *nipple* formed of pure soft graphite, as may be demonstrated by taking any negative carbon after it has been in use, and employing it as a lead pencil. In most cases, sufficient graphite will have collected on the end to permit it to be used for this purpose for several hours.

250. The main source of light in the voltaic arc is the crater in the positive carbon, i.e., the point of highest temperature; for, as we have seen, the light emitted by a heated body increases as its temperature rises. Therefore, in arranging a lamp for the purposes of illumination, the positive carbon is generally made the upper carbon, so that the greatest amount of light can be utilized by being thrown downwards. Practice has shown that, under most circumstances, it is more economical to maintain the carbons a sufficient distance apart to prevent the negative nipple from coming too close to the positive crater and thus obscuring the light. About 85 per cent. of the light of a carbon arc comes from the surface of the positive crater. Since the temperature of the crater is necessarily that of the volatilization of carbon, which is practically a fixed temperature, the amount of light emitted by the crater will be approximately proportional to the active area of the crater. Assuming that none of the light is hidden in transmission, the larger the crater the stronger the current strength in amperes, which will be necessary to keep its entire surface glowing. From these circumstances, an effort has been made to determine the candle-power of an arc lamp from the size of the crater. And, roughly, one square inch of crater surface emits as much light as 100,000 candles. If the size of the crater depended only upon the strength of the current, this might serve

roughly as a guide for the determination of the candle power of an arc lamp; but, unfortunately, the size of the crater has been found to be also dependent on the character of the carbon employed.

Arc lamps are generally commercially rated according to their candle-power, as the so-called 600, 1200 and 2000 candle-power arcs. This method of rating is, unfortunately, unreliable. Strictly speaking, this rating means that a 2000 candle-power arc, for example, will give a light such as would be produced by 2000 candles concentrated at a point, only when set at the most favorable inclination, and when burning under the most favorable circumstances with proper carbons.

251. All portions of the filament of an incandescent lamp have the same temperature, and consequently emit equal quantities of light per unit surface. This is not true of the arc light, since the positive and negative carbons differ greatly in temperature. It follows from this that an incandescent lamp will give out, roughly, the same intensity of light in all directions, while in an arc light, the intensity of light will differ greatly in different directions. The source of light in the arc being on the inside of a cup-shaped electrode, the arc will give out no light in the direction of the depression, and will give out its maximum light in the opposite direction, i. e., facing the depression. In the intermediate plane at right angles to the carbons, or what corresponds to the horizontal plane when the lamp is hung up with the carbons vertical, the amount of light emitted is quite small. Thus, a 2000 candle-power arc lamp, giving 2000 candles in the direction O C or O F, Fig. 100, of maximum intensity, would give probably only about 220 candles in the hori-

zontal plane O J, and probably only 200 candles in the upward directions O A or O H. The *mean candle-power*, or, as it is usually called, the *mean spherical candle-power* may be determined from the average of a sufficiently great number of measurements taken in all directions, and for a 2000 candle-power arc would probably be 700 candles or only about one-third of the maximum.

Although we have spoken of the incandescent lamp as being roughly equally powerful in all directions, yet the mean spherical candle-power of an incandescent lamp is

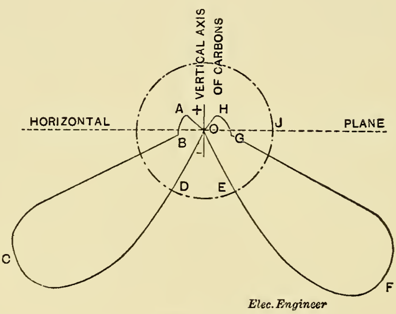


Fig. 100.
Diagram Indicating Luminous Intensity of an Arc Lamp in Different Directions.

about twenty per cent less than the maximum horizontal candle-power, or that which it emits in a horizontal plane at right angles to the filament.

In view of the difficulty which exists in accurately defining and measuring the candle-power of arc lamps, they are sometimes rated entirely by their electrical properties. For example, a 45-volt, 10-ampere lamp, that is, a lamp which absorbs 450 watts, is called a 450-watt arc of 45 volts.

252. The carbon electrodes employed commercially for arc lighting are made from mixtures of powdered coke, charcoal and carbonizable liquids made into a stiff paste and moulded, or forced by heavy hydraulic pressure through dies. These rods, after being dried, are submitted to carbonization by a high temperature in a furnace while protected from the air.

The steadiness of the voltaic arc depends on the steadiness of the current supplying it, on the perfection of the lamp-feeding mechanism, on the character of the carbons in so far as this influences the quantity of vapor liberated in a given time, and on the position of the arc. Unless the carbons are carefully made, soft spots will occur throughout their mass, which when reached will suddenly evolve a larger proportion of carbon vapor and thus tend to render the light unsteady. At the same time these irregularities in the composition of the carbon, will tend to make the arc lose its central position and to travel, or move about from one side to another of the electrodes. This unsteady travelling of the arc may be avoided by purposely forming the centre, or core of the positive carbon, of a softer material by introducing into the substance of the pencil or rod a core made of softer material. The presence of this softer core retains the arc in an approximately central position. such carbons are called *cored carbons* in contradistinction to the ordinary or *coreless carbons.* On account of their expense, cored carbons have not come into extensive commercial use in the United States.

253. Since, while the arc is maintained between them, the carbons are exposed not only to the disruptive action of the current, which is especially apt to break

off portions at their edges, but is also exposed to burning, unless their surfaces are protected in some way the carbons are apt to consume and disintegrate irregularly, becoming pointed and particles being thrown off in powder, thus not only causing a more rapid consumption of the carbons, but also seriously interfering with the proper feeding of the lamp. To avoid this, the surfaces of the carbons are generally coated with a thin electro-plating of metallic copper. This coating decreases the resistance of the carbons, increases their life about 25 per cent., and permits an inferior carbon to be employed more successfully than could otherwise be done.

254. The consumption of the carbons during use in a lamp is due to two causes; namely, (1). Volatilization, and (2), Burning in the air. The positive carbon is consumed by both of these causes, the negative mainly by the latter. The positive carbon, therefore, consumes more rapidly than the negative; roughly, about twice as fast. The length generally given to the positive carbons is twelve inches, and to the negative carbons about seven inches. The rate of consumption will vary with the character of the carbon and the strength of the current, but ordinarily the consumption is about two inches an hour, both carbons included.

At this rate, during prolonged runs in Winter, a single pair of carbons would not be sufficient to last from half an hour after sunset to half an hour before sunrise; consequently, the employment of a single pair of such carbons would necessitate the recarboning of the lamps during their operation. In order to avoid this, a number of expedients have been adopted, such, for example, as the

use of carbon plates instead of rods, or, with a view of decreasing the rate of consumption of the carbon, very thick rods have been employed. But under such circumstances the tendency of the arc to travel either from one side of the plate to the other, or around the extended area of the ends of the rods, results in such an unsteadiness of the light as to render these methods of prolonging the life of the carbons, inapplicable, and has led to the adoption of the *double-carbon* or *all-night lamp* now generally employed in commercial lighting. In this lamp two pairs of carbon electrodes placed vertically over one another are employed, and so arranged that one pair only can come into contact, the other pair being separated a short distance and maintained at this distance until the first pair is consumed, when the current is automatically switched into the new pair.

Carbons are made of different sizes, according to the strength of current employed and the duration required. They vary in diameter from $\frac{1}{4}$ in. to $1\frac{1}{2}$ in., the largest being only employed in powerful search lights.

255. During use, the carbons are almost always placed vertically over each other, though in the early forms of arc light, as in the Jablochkoff candle, they were placed parallel and side by side, being maintained at a constant distance apart by the insertion of a mass of kaolin between them. Carbons have also been placed obliquely to one another at different angles.

A common form of single carbon lamp arranged for street lighting, is provided with a hood which not only protects the lamp mechanism from the weather, but also aids to some extent in reflecting the light downwards.

256. In one form of double-carbon, or all-night lamp, when the current is sent through the lamp, the pair of carbons which are in contact begin to feed, and continue in operation until consumed, when the other pair, which before were separated, are automatically brought into operation.

Syllabus.

The current in a voltaic arc is not maintained through air, but through a mass of carbon vapor, separating the positive and negative carbons.

By the action of the current the positive carbon, usually the uppermost, is hollowed out, while a projecting nipple of pure graphite is formed on the opposed surface of the negative carbon.

Arc lamps are usually rated in candle-power. The nominal power of an arc lamp is assumed to represent the candle-power obtainable from the lamp under the most favorable conditions as to direction, steadiness, and quality of carbon.

Laboratory of Houston & Kennelly,
Philadelphia.

WEEKLY.

No. 29. DECEMBER 29, 1894. Price, - 10 Cents. Subscription, $3.00.

Electrical Engineering Leaflets,

—BY—

Prof. E. J. Houston, Ph. D.
AND
A. E. Kennelly, F. R. A. S.

ELEMENTARY GRADE.

ARC LIGHTING.

---

257. Series-connected arc lamps are usually operated at high pressures. In practice, it is common to operate as many as 65 lamps in series, representing a total E. M. F. of, say, 3,250 volts, and it is not unusual to operate 100 lamps in series. In a few instances the number reaches 200, thus representing a total E. M. F. of about 10,000 volts.

If the insulation of an entire continuous-current arc circuit, could be permanently maintained, there would be no danger in accidentally touching the circuit at any point, but since even the most carefully constructed circuits may become grounded at some point, care should be taken not to come in contact with any portion of an active circuit, unless either rubber gloves are worn, or other equivalent protection is adopted, since, when standing on damp ground, or on a metal plate making ground connection, the current thus received through the body when an accidental contact is made might prove fatal. When,

Published by
THE ELECTRICAL ENGINEER,
203 Broadway, New York, N. Y.

[Entered as second-class matter at the New York, N. Y., Post Office, June 14, 1894.]

therefore, it becomes necessary to adjust a lamp in the circuit, it is desirable to short-circuit the lamp and thus entirely disconnect it from the circuit by means of a switch provided for this purpose. In some cases, as in the illumination of the inside of a building the arc lamps are supplied through a special cut-out switch, especially arranged for this purpose, usually placed on the outside of the building. A form of such cut-out switch is shown in Fig. 101. When the hook H, is pulled down, it first bridges across the mains, and then disconnects the service wires of the building.

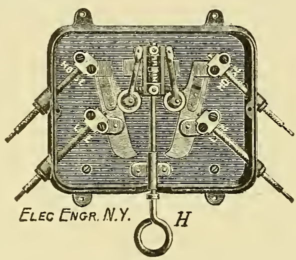


FIG. 101.
Form of Cut-Out Switch.

258. Series-arc lighting is generally employed for operating arc lamps at a considerable distance from the centre of supply, because in this system, the total amount of activity, measured in watts, which is to be distributed, can be supplied by a small current through a small conductor at a high pressure, instead of by a large current through a large conductor at a small pressure, as would be necessary in a system of multiple distribution. The size of wire employed in series-arc lighting is, commonly, No. 6 A. W. G., which has approximately a resistance of 2 ohms per mile (Sec. 42). A series circuit, ten

miles in length, would have a resistance in its conductors of about 20 ohms. With ten amperes flowing through the circuit, the drop in this resistance would amount to 200 volts in all, representing an activity of 200 volts multiplied by 10 amperes, or 2,000 watts. If 100 lamps are operated in this circuit, each taking 50 volts, the activity absorbed by each lamp would be 50 volts × 10 amperes = 500 watts, and the total activity in the lamps 50,000 watts. With ten miles of wire there would be a delivery of 50,000 watts (50 KW.) to the lamps out of a total of 52,000 watts (52 KW.), or an efficiency of delivery of approximately 96 per cent., representing 4 per cent. of the activity lost in heating the conductors. If the same lamps had to be supplied in multiple arc, the current required from the dynamo would be 10 amperes for each lamp, or 1,000 amperes in all, and, in order to obtain the same *efficiency of delivery*, that is, the same percentage of activity wasted in the conductor, it would be necessary to employ two wires along the circuit, each about 1,250 times heavier than the previous single No. 6 wire, or to employ about 2,500 times more copper.

259. In many cases, however, where a low pressure system of incandescent lighting is in existence, as, for example, a three-wire system through the streets of a city at a total pressure of 230 volts, it may be more economical to operate arc lamps in multiple-series, from such a system, than to employ a special series circuit and generator for the arc lamps exclusively. In such cases, arc lamps are supplied from incandescent circuits, two in series from 115 volt mains, or four in series from 230 volt mains. A small resistance is inserted in the circuit of each arc lamp so as to control the current strength

under all conditions of feeding. Such a pair of arc lamps operated from 110 volt mains, through a cut-out switch is represented in Fig. 102. Such lamps are not dangerous to handle, except in so far as may result from accidental contact between the wires of the low tension system and some neighboring high tension system.

260. Arc lamps are sometimes operated from alternating-current circuits. In such cases it is necessary to operate each lamp upon the secondary circuit of

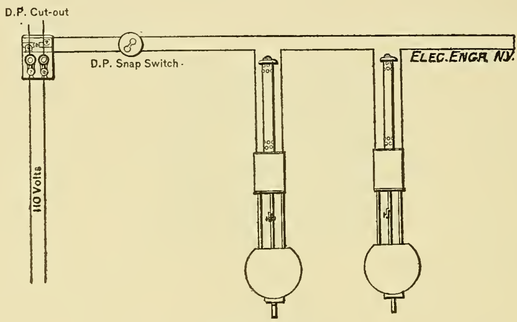


Fig. 102.
Incandescent Circuit, with Standard Lamps.

a small transformer, and to connect all the primaries of such transformers in one series supplied by an alternator at the station: The pressure at the terminals of an alternating current arc lamp, is usually less than the pressure at the terminals of a continuous current arc lamp, and varies from 28 to 35 volts. The current strength through the lamp usually varies from 7 to 14 amperes. Since the direction of current in an alternating current circuit, reverses from 5,000 to 17,000 times per minute, it is clear that each carbon is alternately positive and negative, and neither crater nor nipple is definitely formed at either

electrode. The carbons, therefore, burn away with fairly blunt points.

261. The light emitted by an alternating-current arc not only fluctuates with variations in the length of the arc and its position between the two electrodes, but it also pulsates with every alternation of the current, although these pulsations may be too rapid to attract observation. The light from an alternating current arc instead of being principally directed at an angle of about

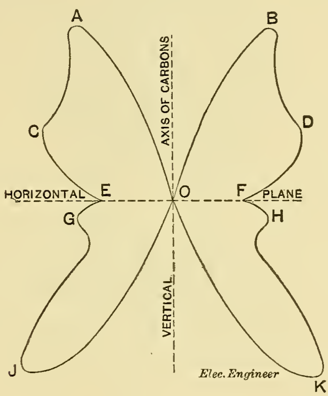


Fig. 103.
Distribution of Light from an Alternating Current Arc as measured in a particular case.

50° below the horizon, as in the continuous current arc is more evenly distributed, and possesses two directions of greatest intensity, one above, and one below the horizon, as represented by Fig. 103, which shows the distribution of light from an alternating current arc in a particular case. The distribution varies greatly with the quality and size of the carbons, the length of the arc, and the circuit upon which the arc lamp is operated. Alter-

nating current arc lamps usually give a humming sound, whose pitch depends upon the frequency of alternation.

262. Arc lamps are commonly enclosed in globes, which not only protect the lamp from the weather, but also distribute the light with a greater uniformity than would otherwise be obtained. Opalescent globes still more thoroughly diffuse the light. The loss of light occasioned by a globe will vary from ten to sixty per cent., according to its dimensions and opacity.

Arc lamps are distributed along thoroughfares at distances which depend upon the width of the streets and the amount of traffic through them. Common distances in city streets being from 200 to 1,000 feet.

263. The great penetrating power, i. e., the high intensity of the arc lamp is frequently utilized in light houses and in search-lights. In such cases the object is to take as much as possible of the light produced by the arc and to direct it into a single beam, so as to prevent it from being rapidly lost by diffusion in all directions. This is sometimes accomplished by lenses, or reflectors, or by both combined, but the most modern apparatus employs large lenses only. It was at one time necessary to employ lenses of parabolic form, of the type represented in the headlights of locomotives, but more recently a method has been introduced of employing large lenses, whose surfaces are produced as nearly spherical as possible and, therefore, surfaces that can be obtained at greatly reduced cost. Fig. 104 shows a form of search-light projector in general use. The direction of the beam is controlled by supporting the projector upon a " Y ", which rotates about a vertical axis in the base. By the handle

H, the projector can be thrown upwards or downwards. A spherical lens is contained at the back of the projector and the front is closed by strips of plane glass. In clear weather, with good adjustments, the total quantity of light in the beam remains practically the same for many miles, but, as it is impossible to produce a perfectly parallel beam, its area necessarily increases with the distance from the apparatus, and the illumination produced there-

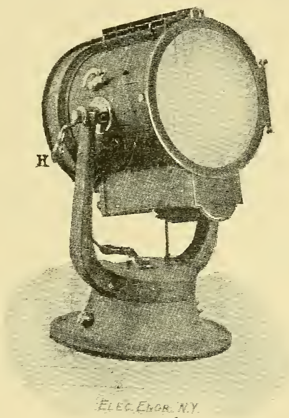


FIG. 104.
Form of Projector.

fore diminishes rapidly with the distance. The projector shown has a diameter of 18 inches, but they have been constructed of as large a diameter as 60 inches. The distance at which such a beam can be utilized for signalling purposes in clear weather at night time, is limited only by the rotundity of the earth.

The largest projectors employ currents of 200 amperes and carbons about one and a quarter inches in diameter.

SYLLABUS.

The amount of copper required to supply long circuits of arc-lights at a given efficiency is much less when the lamps are connected in series, than when they are connected in multiple.

Arc lamps in cities are frequently supplied more economically in multiple-series from low-tension incandescent systems, than from separate series circuits.

Arc lamps supplied from alternating current circuits require from 28 to 35 volts.

Alternating current arc lamps distribute their light more uniformly in all directions than continuous current arc lamps, but usually emit a humming sound.

Globes covering voltaic arcs, absorb from 10 to 60 per cent. of the light emitted.

Laboratory of Houston & Kennelly,
Philadelphia.

WEEKLY.

No. 30. JANUARY 5, 1895. Price, - 10 Cents. Subscription, $3.00.

Electrical Engineering Leaflets,

—BY—

Prof. E. J. Houston, Ph. D.
AND
A. E. Kennelly, F. R. A. S.

ELEMENTARY GRADE.

Alternating Currents.

264. In a continuous current circuit, as we have seen, the directions of the E. M. F. and current remain the same. In an alternating current circuit, however, both the direction of the E. M. F. and of the current rapidly reverse, being alternately positive and negative. For example, an ordinary *alternator*, i. e., a machine, for producing alternating currents, if supplying 1100 volts to an incandescent lighting circuit, generates an E. M. F. which changes from about 1550 volts positive to about 1550 volts negative, perhaps some 260 times in each second. If the current supplied to the circuit by this E. M. F. be, say, 50 amperes, this current will also change from a maximum of, perhaps, 70 amperes positive to 70 amperes negative, the same number of times in a second.

The changes, or the reversals, in the direction of the E. M. F. or current, are called *alternations*. Thus, a machine is spoken of as producing 16,000 alternations per minute. Such a machine would reverse its current

Published by
THE ELECTRICAL ENGINEER,
203 Broadway, New York, N. Y.

[Entered as second-class matter at the New York, N. Y., Post Office, June 14, 1894.]

16,000 times per minute, or would produce 8,000 waves in one direction and 8,000 waves in the opposite direction. A double-reversal, or complete to-and-fro motion, is called a *cycle*, so that the preceding machine would be said to produce 8,000 cycles per minute. In electrical engineering, however, an alternator is generally described by the number of cycles it produces per second, rather than its number of cycles per minute, and this number is commonly called the *frequency of alternation*. Thus, a machine producing 8,000 cycles per minute, produces $133\frac{1}{3}$ cycles per second, or, as it is commonly

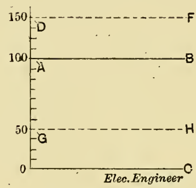


FIG. 105.
Graphic Representation of Continuous E. M. F.'s or Currents.

written, a frequency of $133\frac{1}{3}\sim$. The time required to complete one cycle, or double alternation, is called a *period*. It is clear that if a machine produces one cycle in a period of $\frac{1}{100}$ of a second, it will produce 100 cycles in a second, or, that its frequency will be $100\sim$. So that in all cases the period will be 1, divided by the frequency. For instance, a generator which possesses a frequency of 60 would have a period of $\frac{1}{60}$ second.

265. When a continuous current generator produces a steady E. M. F. of 110 volts, this E. M. F. may be represented graphically by a straight line A B, drawn parallel to the base O C. Fig. 105. If the E. M. F. instead

of being 110 volts were 150 volts, then it would be represented by a straight line D F, situated above the line A B, while a continuous E. M. F. of 40 volts would be represented by a straight line G H. All these lines, while they are situated at distances from the base O C, which represent the magnitudes of the respective E. M. F.'s, are all above O C, and, therefore, have the same direction, and correspond to positive E. M. F.'s. If, for example, it were required to represent an E. M. F. of 40 volts negative, or in the opposite direction to that

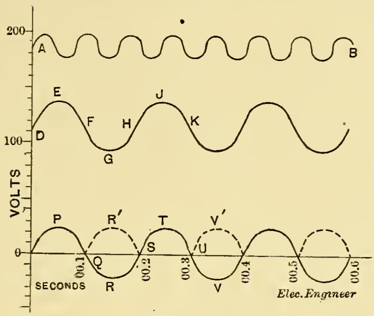


FIG. 106.
Graphical Representation of Pulsatory and Alternating E. M. F.'s or Currents.

represented by the line G H, it would be necessary to draw the line as far below O C, as G H is above it. If the E. M. F. instead of being constant, fluctuates or pulsates, it may be represented by the waving line A B, Fig. 106, where the E. M. F. is seen to vary rapidly between 175 and 200 volts, or the fluctuations may be much greater, as in the case represented by the wavy line D E F G H J K, where the E. M. F. varies periodically between 90 and 140 volts. Such an E. M. F. is called *fluctuating* or *pulsatory*, so long as the waves do not descend below the horizontal

line ; that is, so long as the E. M. F. or the current does not change direction, however much it may change its magnitude.

When, however, the E. M. F. or current periodically changes both in direction and magnitude it is said to be an *alternating* E. M. F. or *current.* Thus in Fig. 106, the E. M. F. is seen to change from 23 volts in the positive direction to 23 volts in the negative direction, each wave occupying just $\frac{1}{100}$th of a second, so that the period, or the time occupied in completing a cycle is $\frac{1}{50}$ of a second and the frequency is 50 ∼.

266. The change in the direction of the E. M. F. or current, that is, its change from positive to negative, may take place in an infinite number of ways. Thus,

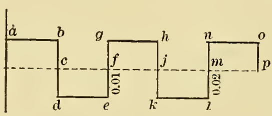


FIG. 107.
Periodic Alternating E. M. F. or Current.
Rectangular Type.

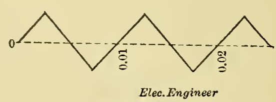


FIG. 108.
Periodic Alternating E. M. F. or Current.
Zig-zag Type.

the E. M. F. may retain its full strength during the alternation, suddenly reversing to the full strength in the opposite direction, as shown in Fig. 107. Or, it may rise and fall steadily so as just to reach the full strength in the opposite direction, as shown in Fig. 108. In practice, however, the wave usually possesses an intermediate form as shown in Figs. 109, 110 and 111, where the changes are neither abrupt nor constant, but follow a definite curve. Fig. 111 represents a particular form of wave, called a *sinusoidal* wave, because the curve

shown is what is known geometrically as a *sinusoidal* curve.

In practice, *alternators*, that is, alternating current generators, do not generate strictly sinusoidal E. M. F.'s, but some type of wave comprised between the curves of Figs. 109 and 110. For the purposes of calculation, however, these waves are usually regarded as being approximately sinusoidal.

Of whatever shape may be the waves of E. M. F. produced by an alternator, they are invariably symmetrical, if the mechanical construction of the field and armature

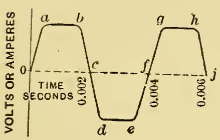


Fig. 109.
Periodic Alternating E.M.F. or Current.
Flat-Topped Curve.

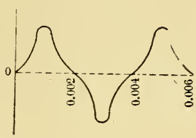


Fig. 110.
Periodic Alternating E.M.F. or Current.
Peaked Curve.

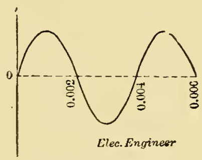


Fig. 111.
Periodic Alternating E.M.F. or Current.
Sinusoidal Curve.

are symmetrical. That is to say, each positive wave is of the same shape as the negative wave, the two differing only in direction. It is possible, however, that owing to some dissymmetry of mechanical construction in an alternator, the E. M. F. waves it generates may not be quite symmetrical, but in any case the area of the waves when graphically outlined must always be the same; so that, assuming an alternator to produce the E. M. F. waves of the character represented in Fig. 109, but that by reason of dissymmetrical construction, the positive waves, or those drawn above the zero line *o j*, were flatter than the negative waves drawn below the

zero line, yet it would necessarily happen that the area of any positive wave, such as *o a b c*, measured on the paper in square inches, would be equal to the area of any negative wave, such as *c d e f*.

267. If an alternating E. M. F. had a rectangular wave type, represented by Fig. 107, in which each vertical distance *o a*, *n m*, or *j k*, stands for say 50 volts, then the value of the alternating E. M. F. would evidently be 50 volts, since at no time during the cycle would there be an E. M. F. of a value of less than fifty volts impressed on the circuit in one direction or the other. If, however, an E. M. F. were of the type shown in Fig. 108, the E. M. F. would only have the value of 50 volts momentarily at the tops of the waves, and the mean E. M. F. could not possess a value as high as 50 volts. It becomes necessary, therefore, to define conventially the value of an E. M. F. of this type, or of any of the types shown in the Figs. 109, 110 and 111.

268. If it were possible, by means of a commutator, to reverse all the alternate waves of E. M. F. or current, so as to produce a pulsatory E. M. F. or current, as shown in Fig. 106 by the curve O P Q R ′ S T U V ′, then, by sending such a current through a plating bath, the average current strength could be determined by ascertaining the number of coulombs passing through the circuit. (Sec. 54.) Or, if sent through an ammeter of the ordinary magnetic type, the average current strength might be similarly obtained. Such value might be called the *mean strength* of the E. M. F. or current. Practically, however, it is the heating power of an alternating current which is taken to determine its value. That is to

say, the number of amperes in an alternating current is equal to the number of amperes in a continuous current, which possesses the same heating power, and this eliminates all questions as to the shape of the alternating current wave. In a sinusoidal E. M. F. or current, the effective strength is approximately 71 per cent. of the maximum current strength in the wave, so that a sinusoidal E. M. F. of 710 volts effective, would generate approximately 1,000 volts at the peak of each wave. Again, a sinusoidal current, which had a maximum value of one ampere at the peak of each wave, would have an effective value of approximately $\frac{7}{10}$ths ampere, and would, therefore, produce as much heat in a resistance as $\frac{7}{10}$ ampere of continuous current. This is why an incandescent lamp gives the same candle-power upon a continuous or alternating current circuit of the same effective voltage, because the value of the alternating current E. M. F. is chosen by its heating effect, and without regard to the maximum value it may obtain in the cycle.

In other types of alternating current waves, this relation between the effective and maximum value is not maintained. For example, in the ideal type represented in Fig. 107 the effective strength would coincide with the maximum strength, and in Fig. 108 the effective strength would be approximately 58 per cent. of the maximum strength. It usually lies between 60 and 80 per cent.

Syllabus.

A continuous E. M. F. or current possesses constant magnitude and direction.

A pulsatory or fluctuating E. M. F. or current possesses fluctuating magnitude but constant direction.

An alternating E. M. F. or current has periodically varying magnitude and direction.

The time occupied in executing a double alternation or cycle is called a period.

The number of periods executed in one second is called the frequency.

Commercial frequencies vary between 25 and 133 ~ per second.

The effective strength of an E. M. F. or current is the corresponding strength of continuous E. M. F. or current which would produce the same heating effect.

Alternating E. M. F.'s or currents may vary between 50 and 100 per cent. of the maximum value in each wave, and usually vary between 60 and 80 per cent.

Laboratory of Houston & Kennelly,
Philadelphia.

WEEKLY.

No. 31. January 12, 1895. Price, - 10 Cents. Subscription, $3.00.

Electrical Engineering Leaflets,

—BY—

Prof. E. J. Houston, Ph. D.
AND
A. E. Kennelly, F. R. A. S.

ELEMENTARY GRADE.

Alternating Currents.

269. When two continuous current generators are connected together in series (Sec. 76) the E. M. F. produced is equal to the sum of their separate E. M. F.'s. Thus, if a 150-volt and a 50-volt continuous-current generator are connected in series, their combined E. M. F. will be 200 volts. When two alternating-current generators, in series, having the same frequency, are coupled rigidly together on the same shaft, the E. M. F. produced will not be the sum of their separate E. M. F.'s unless the two machines are so coupled as to be exactly in *phase*, or in step with each other; that is, unless they reach the crests and troughs of their E. M. F. waves at exactly the same instant. Under such conditions, two, one-thousand-volt generators, of say 125 ∼, will develop together a total E. M. F. of 2,000 volts and 125 ∼. At any other phase relationship, that is, when the machines are out of step, the sum of their E. M. F.'s will be less than the arithmetical sum of the two separately. If the two machines are

Published by
THE ELECTRICAL ENGINEER,
203 Broadway, New York, N. Y.

[Entered as second-class matter at the New York, N. Y., Post Office, June 14, 1894.]

exactly out of step half a period (180° out of phase) then, since one machine will be generating a positive wave, while the other is generating a negative wave of the same magnitude, the two will exactly neutralize each other, and no resultant E. M. F. will be developed by them in series. At any intermediate difference of phase (less than 180°) some E. M. F. will be produced less than 2,000 volts.

270. Thus, if a line A B, Fig. 112, one inch long, represents an effective alternating E. M. F. of 1,000 volts, produced by one alternator, and the line B C, also

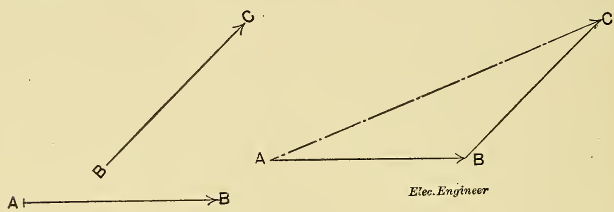


FIG. 112.

one inch in length, represents an effective E. M. F. of 1,000 volts supplied by a second alternator having the same frequency, but a phase of 45°, or $\frac{1}{8}$ cycle, $\left(\frac{360°}{8} = 45°\right)$ in advance, so that the line B C, is inclined upward at an angle of 45° relatively to the direction of A B; then, if we couple the two lines A B and B C, rigidly together, just as the two alternators are coupled rigidly together, at this phase angle, the resultant E. M. F. will be the line A C, measuring $1\frac{85}{100}$ inches in length, and, therefore, representing an effective E. M. F. of 1,850 volts. If the two machines are coupled in quadrature, as shown in

Fig. 113, D E and F G, being each one inch long as before, but the angle being 90°, or $\frac{1}{4}$ cycle $\left(\frac{360^\circ}{4} = 90^\circ\right)$ instead of 45°; the resultant E. M. F. produced by coupling these two machines together in quadrature is shown by the line D G, measuring $1\frac{41}{100}$ inch and, therefore, representing 1,410 volts. In the same way the sum of any two separate alternating E. M. F.'s is their *geometrical* sum.

271. Ohm's law does not apply to the alternating-current circuit, unless some corrections are first introduced. When an alternator, delivering 1000 volts effec-

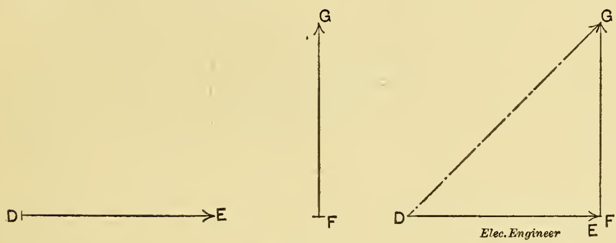


FIG. 113.

tive at its terminals, as measured by a suitable voltmeter, is connected to a coil of insulated copper wire, having a resistance of 100 ohms, we should expect by Ohm's law to find that the current strength passing through the coil would be $\frac{1000}{100} = 10$ amperes. In point of fact, an ammeter introduced into the circuit would show less, perhaps, only five amperes. It is evident, therefore, that there has been introduced into the circuit what practically amounts to an additional resistance of 100 ohms, and that the apparent resistance of the circuit

is 200 ohms. This apparent resistance is called the *impedance* of the circuit. The impedance of a circuit is usually greater than its resistance and depends upon the nature of the circuit and upon the frequency.

272. In some cases the impedance of a circuit may be less than the resistance; for example, a *condenser* has a definite and moderate impedance for alternating currents, while its resistance may be extremely great.

A condenser consists of two opposed metallic surfaces separated by a thin sheet of insulating material. Such an arrangement is diagrammatically shown in Fig. 114, where five metallic sheets are separated by four sheets

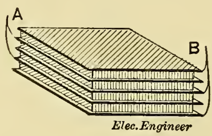


Fig. 114.

of insulating material, such as glass, mica, paraffined paper, etc. The effective area of the condenser shown is four times the area of the top plate. The metal plates are connected alternately to the terminals A and B. The *capacity* of a condenser increases with the effective area and with the thinness of the insulating sheets.

273. When an alternator is connected directly to a resistance, consisting practically of conductors without many turns, termed an *inductionless resistance*, as, for example, a series of incandescent lamps, Fig. 115, then the current strength produced will be practically defined by Ohm's law. Thus, if the 1000-volt alternator previously described, be connected to such a resistance, for

example, to a series of ten 100-volt incandescent lamps, offering a resistance when hot of 2000 ohms, the current passing through the lamps will be $\frac{1000 \text{ volts}}{2000 \text{ ohms}} = \frac{1}{2}$ ampere, and the impedance of this circuit is the same as its resistance.

274. If, however, the lamps be replaced by a coil of wire with or without an iron core, Fig. 116, having a resistance of 500 ohms, the current strength will be less than $\frac{1000}{500}$ or 2 amperes, because the magnetic flux, generated by the alternating M. M. F. of the coil,

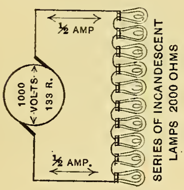


FIG. 115.

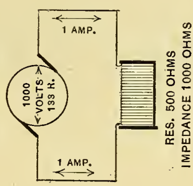
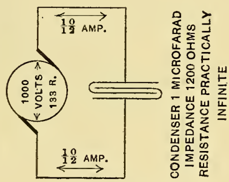


FIG. 116.



Elec. Engineer

FIG. 117.

rapidly filling and emptying the loops of the coil, generates in them a C. E. M. F., (Sec. 207), acting as a resistance, thus apparently increasing the resistance of the circuit to the observed impedance. Since the value of the C. E. M. F. developed in the coil depends upon the rapidity of change in the flux, and this in turn depends upon the frequency of alternation, the greater the frequency of alternation, the greater will be the impedance of the coil. It is now clear why an inductionless circuit has its impedance no greater than its resistance, since there is scarcely any self-induction

possible ; that is, no turns with which flux from the circuit can be looped in which to develop C. E. M. F.. This is also the reason why an alternating-current transformer, with a primary whose resistance may be 25 ohms, when connected to the primary mains of an alternating current curcuit at 1000 volts pressure, only receives, say, $\frac{1}{2}$ ampere of current, when no load is on the transformer, since the primary circuit of a transformer consists of a number of turns of insulated wire, closely linked with a heavy laminated iron core, so as to develop a very considerable self-inductance and C. E. M. F. In fact the impedance of the coil, may be, under the above mentioned circumstances, perhaps 2000 ohms, or 80 times greater than its resistance.

275. A condenser of one microfarad capacity, that is, the one millionth part of a farad, or, a condenser which will take a charge of one-millionth of a coulomb, (Sec. 54) when charged under a continuous-current pressure of one volt, will, if connected to the terminals of an alternator supplying a pressure of 1000 volts at a frequency of 133 $\sim$, Fig. 117, receive, a current of about $\frac{10}{12}$ ampere, and will, therefore, have an impedance of about 1200 ohms, although its resistance to a continuous current would be practically infinite after the first charge. The effect, therefore, of inserting into a circuit a condenser whose capacity is suitably chosen, is to diminish the impedance of the circuit and increase the current strength. On the other hand, the effect of introducing an inductance, or *choking coil*, into a circuit containing resistance, is to increase the impedance and diminish the current strength. A condenser and an in-

ductance are, therefore, often capable of neutralizing each others effects.

276. A form of choking coil called a *regulator* is shown in Fig. 118. It consists of a long coil, divided into sections, and provided with an iron core, which can be pushed in or out by means of a handle. When the core is pushed into the section in use, which is traversed by an alternating current, the inductance of the coil is greatly increased by diminishing the reluctance of its magnetic circuit, and enabling the same M. M. F. to produce a much greater magnetic flux linked with its

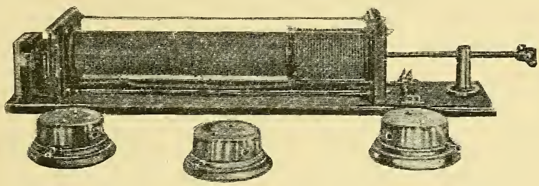


FIG. 118.

turns. The increased magnetic flux produces a greater C. E. M. F. and, therefore, a greater impedance in the circuit.

277. When a condenser, and a resistance containing inductance, are connected in series to an alternating E. M. F., of, say, 100 volts, it may readily happen that the pressure across the condenser terminals may be, say, 60 volts, and the pressure across the terminals of the choking coil, say, 70 volts, so that the total drop in the circuit, regarded from the usual standpoint of a continuous current circuit, would be 130 volts, or 30 volts more than that measured across the terminals of the alter-

tor. The reason for this discrepancy is owing to the fact that the C. E. M. F., or drop at the terminals of the condenser, is not in phase with the C. E. M. F. or drop at the terminals of the coil, and just as the two alternators when connected in series, out of step, give a total E. M. F. less than their arithmetical sum, so the total of these two C. E. M. F.'s which are out of phase, is less than their sum, and exactly equal to the impressed E. M. F.

Syllabus.

The total E. M. F.'s of continuous-current generators connected in series is the sum of their separate E. M. F.'s.

The total E. M. F. of alternating-current generators, connected rigidly in series, is less than the sum of their separate E. M. F.'s, unless all the separate alternators are rigidly connected in the same phase.

The resistance of a continuous-current circuit becomes modified when an alternating current passes through it.

The current strength in an alternating-current circuit is expressed by amperes $= \dfrac{\text{E. M. F. in volts.}}{\text{Impedance in ohms.}}$

The impedance of a resistance containing inductance is greater than its resistance.

The impedance of a condenser is less than its resistance.

Consequently a condenser and an inductance frequently tend to neutralize each other when introduced into the same circuit.

Laboratory of Houston & Kennelly,
Philadelphia.

WEEKLY.

No. 32. JANUARY 19, 1895. Price, - 10 Cents. Subscription, $3.00.

Electrical Engineering Leaflets,

—BY—

Prof. E. J. Houston, Ph. D.

AND

A. E. Kennelly, F. R. A. S.

ELEMENTARY GRADE.

Alternating Currents.

---

278. We have seen that the apparent resistance, or impedance, of an alternating-current circuit is not the same as the resistance of the same circuit to continuous currents, unless the circuit possesses neither inductance nor capacity, that is, unless it practically consists of a straight conductor. All circuits, however, owing to their M. M. F. (Sec. 119), possess some inductance (Sec. 160); that is, some capability of inducing C. E. M. F. in them by the variation of their current strength, for, every circuit must form at least one loop, and the M. M. F. of this loop, as the current alternates, must force magnetic flux to-and-fro through the loop, thereby setting up a C. E. M. F. in the circuit. (Sec. 207.) The amount of the self-induced E. M. F. will depend on the amount of flux linked with the circuit, and this depends

(1.) Upon the M. M. F. of the circuit, and

(2.) Upon the reluctance of the circuit, or the area of the loop or loops, when no iron is present.

Published by
THE ELECTRICAL ENGINEER,
203 Broadway, New York, N. Y.

[Entered as second-class matter at the New York, N. Y., Post Office, June 14, 1894.]

279. Considering any alternating-current circuit, as consisting of a single wire bent into some form of loop, this may be spread out into a circle, as shown in Fig. 119, or flattened into a long, thin, loop, like twin wires, as shown at (2). If, say 10 amperes, pass through the circuit in each case, the M. M. F. of the circuit will in each case be 10 ampere-turns, but the reluctance of the circular circuit will be much less than the reluctance of the twin-wire circuit, since the magnetic flux has a much wider path through the loop. More flux will consequently pass through the circular loop, and this flux, pulsating to-and-fro with the alternations of the current, will generate a greater C. E. M. F. by self-induction in the circular circuit than in the twin-wire circuit.

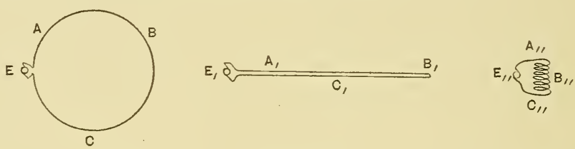


Fig. 119.
Illustrating Inductive and Non-Inductive Alternating Current Circuits.

280. When a circuit consists of more than one turn, as, for example, of a coil as shown in Fig. 119 (3), there is, with the same current strength through the circuit, a greater M. M. F., since there is a greater number of ampere turns, and the flux through the coil will, therefore, be increased. This increased flux will also pulsate through the entire coil. The flux will set up a considerable C. E. M. F. in each turn, so that all the turns being in series, the total C. E. M. F. of self-induction is greatly increased. The C. E. M. F. is still greater, if an iron core be inserted in the coil, or if the coil be wound upon a ring of iron, since the reluctance of the circuit will be

greatly reduced, and the total flux and flux leakage correspondingly increased.

The effect of this C. E. M. F. of self-induction in a circuit is to make the apparent resistance or impedance of the circuit greater than its actual resistance.

A twin-wire circuit, as represented in Fig. 119 (2), unless long, will have a very small inductance. Such a circuit is sometimes called a non-inductive circuit, and its impedance will be practically the same as its resistance to continuous currents. The circular circuit of (1) Fig. 119, will have more inductance than the twin-wire circuit, but if a non-inductive resistance such as an incandescent lamp be inserted, say at B, the impedance of the circuit will be but little in excess of the resistance. Most primary, or high tension, alternating-current circuits are of type (3) having motors or transformers at the point of delivery, and their impedance is, consequently, considerably greater than their resistance.

281. The effect of the C. E. M. F. of self-induction increases with the frequency of alternation, since the rate of change of flux linked with the circuit increases, so that the impedance of the circuit increases as the frequency of alternation is increased. For example, a continuous-current generator of 100 volts E. M. F., connected to a choking coil of 5 ohms resistance, would send, by Ohm's law, a current of $\frac{100}{5} = 20$ amperes through the choking coil. An alternator of 100 volts effective E. M. F. with a frequency of 25 $\sim$ would, perhaps, only send 16 amperes through the coil, indicating that the impedance of the coil at this frequency was $6\frac{1}{4}$ ohms, since $\frac{100}{6\frac{1}{4}} = 16$ amperes. If, now, the frequency of the alter-

nator be increased to 100 $\sim$, retaining the same effective E. M. F. of 100 volts, the current strength through the coil would, perhaps, be only $6\frac{1}{3}$ amperes, indicating an impedance of $\frac{100}{6\frac{1}{3}} = 15\frac{8}{10}$ ohms.

282. When two similar and equal impedances are connected in parallel, their joint impedance is half that of either. Thus, two choking coils, each offering 100 ohms impedance, would, when connected in parallel, offer jointly 50 ohms impedance; but if the two impedances are not of the same kind, that is to say, one is a choking coil and the other a simple resistance or a condenser, the joint impedance may be very different from half of either, since the currents in the two impedances are not in phase. It is in some cases possible to connect a condenser in parallel with a choking coil or transformer so as to have the joint impedance greater than the impedance of either singly, and so that the current supplied to the combination will be less than the current which would be supplied to either the condenser or the choking coil, if one were removed from the circuit.

283. In a continuous-current circuit, the activity, that is, the rate of doing work, is the product of the pressure in volts and the current strength in amperes, so that when, for example, a pressure of 100 volts is connected to an incandescent lamp, taking $\frac{1}{2}$ ampere, the activity in the lamp is $100 \times \frac{1}{2} = 50$ watts. ($\frac{50}{746}$ horse-power.) In an alternating-current circuit, the activity is the same, when the current is in-step with the E. M. F.; that is, when there is no appreciable inductance or capacity in the circuit; so that when the lamp

just considered is connected to a pressure of 100 volts alternating, the inductance of the lamp being negligible, as there is only a single loop in the filament, the C. E. M. F. of self-induction is negligible, and the impedance of the lamp is practically the same as its resistance, while the current is in step with the impressed E. M. F. For this reason a 50-watt incandescent lamp absorbs the same activity, and gives the same light, at equal pressures on continuous or alternating-current circuits; but, when, owing to the presence of appreciable inductance or capacity, the impedance of the circuit differs from its resistance, the current waves will not be in-step with the waves of E. M. F. In a circuit containing inductance and resistance, or a condenser and resistance, the crest of the current waves will respectively fall behind, or advance before, the crests of the E. M. F. waves, by a fraction of a a cycle, representing what is called a leading or a lagging of the current, and the product of the volts and amperes will be greater than the real activity. For example, when an alternating E. M. F. of say 1000 volts, with a frequency of 140 $\sim$, is impressed upon a condenser of 10 microfarads capacity, the current in the condenser will be $8\frac{8}{10}$ amperes, as might be shown by the insertion of a suitable ammeter in the circuit. The product of the volts and amperes in this case would be $1000 \times 8\frac{8}{10} = 8800$, so that if this were the real activity, the power expended would be nearly twelve horse-power, and perhaps thirteen horse-power would have to be expended at the shaft of the alternator over and above that required to divide it on open circuit. Owing to the fact, however, that the current in the condenser is *in quadrature* with the E. M. F., that is, is $\frac{1}{4}$ of a cycle ahead of the E. M. F., correspond-

ing to a lead of 90°, the crests of the E. M. F. waves just coincide with the troughs of the current waves, and vice versa, so that, on the average throughout the cycle, no activity is expended, and the alternator would require no more power to drive it than if its circuit were open. Strictly speaking, there will be some little expenditure of energy in the insulating material of the condenser, which will get warm, and also in the wires and ammeter carrying the current, which will also be warmed, but these losses can be made very small. The lag or lead of a current is always less than one-quarter cycle or 90°.

284. The ratio of the real power, to the apparent power or product of the volts and amperes, is called the *power factor* of the circuit. In the case just cited, the real power expended in the circuit, as measured by a suitably constructed wattmeter, might be 44 watts, and the apparent power would be 8800 watts, so that the power factor for this circuit would be $\frac{44}{8800}$, or half of one per cent. The power factor of a circuit can never exceed unity, or 100 per cent. In alternating-current circuits, supplying transformers for incandescent lighting purposes, the power factor is usually about 95 per cent., so that the product of the volts at the alternator terminals, and the current supplied by the alternator, is usually about 5 per cent greater than the true number of watts expended by the machine. In circuits containing induction-motors, however, which are being operated at a light load, the power factor may be as low as 50 per cent., which means that the current strength supplied to such motors is double that which would be sufficient to operate them if the waves of current and E. M. F. were in-step.

285. When an alternating-current passes through a conductor, it necessarily produces an oscillating magnetic flux around the conductor (see Fig. 56); that is, an alternately right-handed and left-handed circular flux around the wire at each current reversal or alternation. This flux, which is partly within the wire and partly surrounding it, oscillating to and fro round the wire, induces in it a C. E. M. F. At the surface, only the flux oscillating external to the wire can produce C. E. M. F., while at the centre both the external and the internal flux can induce C. E. M. F. Consequently, the C. E. M. F. generated at the central portion or axis of the wire is greater than the C. E. M. F. produced by the weaker flux at the surface. As a result, the impedance offered by the central portions of the wire is greater than the impedance offered by the outer portions of the wire, so that more current passes through the outer portions than through the central portions.

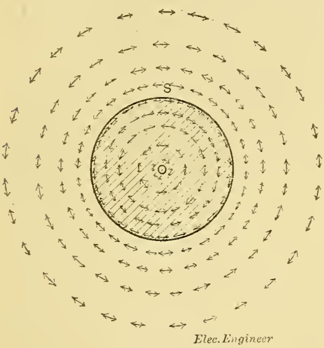


FIG. 120.
Illustrating the production of "Skin Effect" in a wire carrying an alternating current.

Thus Fig. 120 represents the cross-section of a wire carrying an alternating current. The magnetic flux set up by this current is most powerful at the surface S, and diminishes in intensity as we recede from the wire, and also as we proceed downwards towards the axis O, where the flux disappears. The dotted circles indicating some of the flux paths are double-headed arrows, since the flux is alternately right-handed and left-handed. At any

superficial portion s, of the wire all the flux outside s unites, in oscillation, to induce a C. E. M. F. along the wire opposing the alternating current. At the centre o, all the flux, both inside and beyond the wire unites in oscillation to induce a C. E. M. F. along the wire, so that there is more C. E. M. F. at o, than at s.

286. With a large wire or rod of copper, say two inches in diameter, carrying alternating currents of a frequency of 140 ~, we should find that the external layers carried almost the entire current, and that near the axis or the central portion, the current was very feeble. This is called a *skin effect*. The skin effect increases with the frequency, and with the size of the wire. It is also much greater in iron than in copper, other things being equal. At commercial frequencies, however, that is, at frequencies not exceeding 140 ~, the impedance of copper wires ordinarily employed in construction is not appreciably increased by skin effect, for in a No. 000 A. W. G. copper wire, carrying a current of 140 ~, the additional impedance due to skin effect, or imperfect penetration, is only about 1½ per cent., and in a No. 00 copper wire at the same frequency about 1 per cent. Owing to imperfect current penetration, a No. 7, A. W. G., iron wire, may, however, offer double the resistance, that it does for continuous currents, owing to the powerful magnetic flux passing through the substance of the iron wire, and the powerful C. E. M. F. thereby generated in its central portions. The skin effect in the iron wire varies with the current strength, owing to the variations in the reluctance of iron at different flux densities.

Laboratory of Houston & Kennelly,
Philadelphia.

WEEKLY.

No. 33. JANUARY 26, 1895. Price, - 10 Cents. Subscription, $3.00.

Electrical Engineering Leaflets,

—BY—

Prof. E. J. Houston, Ph. D.
AND
A. E. Kennelly, F. R. A. S.

ELEMENTARY GRADE.

ALTERNATORS.

287. In every generator the current in the armature is necessarily alternating. In a continuous-current generator these alternating currents are caused to flow in the same direction in the external circuit, by the aid of the commutator; in an alternator, they are supplied to the external circuit in the condition in which they are generated, and, therefore, alternators dispense with a commutator. In a continuous-current generator the number of poles in the field frame is largely a matter of economy, convenience in construction, and choice. In an alternator, as soon as the frequency of alternation is assigned, and the speed of rotation known, the number of poles is definitely determined. The poles are always alternately north and south around the field frame, and hence the number of poles must be always an even number.

288. Fig. 121 represents a common form of series armature connection employed in alternators. The coils A C D E F G, are rigidly supported on an armature

Published by
THE ELECTRICAL ENGINEER,
203 Broadway, New York, N. Y.

[Entered as second-class matter at the New York, N. Y., Post Office, June 14, 1894.]

frame, rotated past the pole-pieces, which are represented by the letters N and S. It will be seen, by tracing the action, that at the moment when the flux from the north pole is threading through the coils A, D and F, inducing in these coils a counter-clockwise E. M. F., the flux through the south poles is threading through the coils C, E, and G, in the opposite direction, inducing in these coils an E. M. F. similarly directed as regards the circuit. Consequently, the E. M. F.s in all the coils reverse together, and one reversal is produced every time a pole is passed. If, therefore, the armature makes, say 25 revolutions per second, and there are 10 poles in the

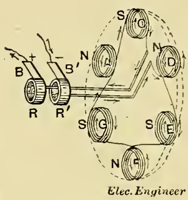


Fig. 121.

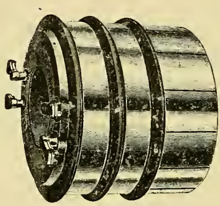


Fig. 122.

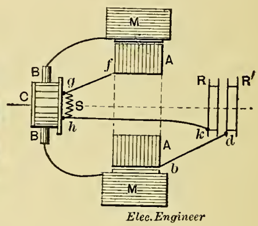


Fig. 124.

field frame, there will be 250 alternations produced per second, or 125 ~. If the ends of the series-connected coils are joined to the collector rings R, R′, the brushes B, B′, will be alternately positive and negative.

289. Although in an alternator no necessity exists for commuting the currents generated, yet, in order to compound-wind the machine, the armature coils are often connected to a shunted commutator for the purpose of supplying the field magnets with a continuous current. Such a form of commutator is attached to the shaft close to the collector rings as shown in Fig. 122.

290. Fig. 123 represents the various parts of a particular form of alternator separated to show them more clearly : (1) is the armature frame ; (2) and (3) the field frame; (4) the sliding bed-plate; (5) pulley and standard; (6) commutator end standard ; (7) the brush-holder stands ; (9) a field spool ; (11) shunt spool ; (12) brush-holder yoke, and brush holders ; (13) the commutator collector ; (14) ratchet ; (15) and (20) bearing caps ; (16)

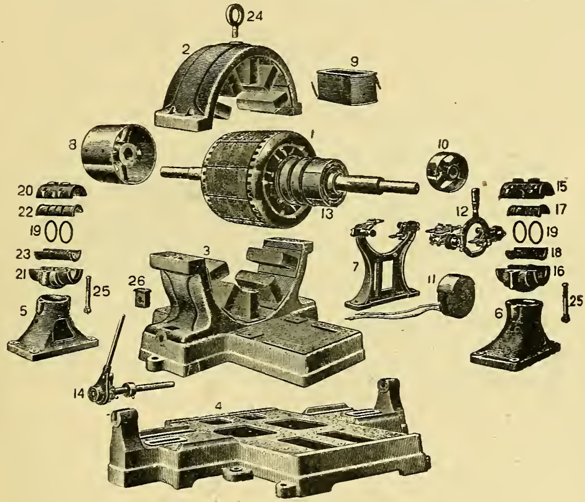


Fig. 123.

and (21) bearings ; (17) (18) (22) and (23) upper and lower linings for bearings ; (1) oil rings ; (25) oil guage ; (26) flat ratchet nut.

This alternator is provided with two windings on its field magnets. One of these is permanently connected to a small continuous-current exciter, which supplies the necessary current to generate the initial E. M. F. of the alternator, and the second winding is connected with the

armature through a shunt around the commutator, as shown in Fig. 124. The current supplied by the armature A passes into the external circuit through the commutator C, which is shunted by a German silver shunt S, so that a portion of the current is commuted and passes through the field magnet circuit M M, thereby increasing the excitation as the load on the alternator increases and so compensating for the drop in the machine.

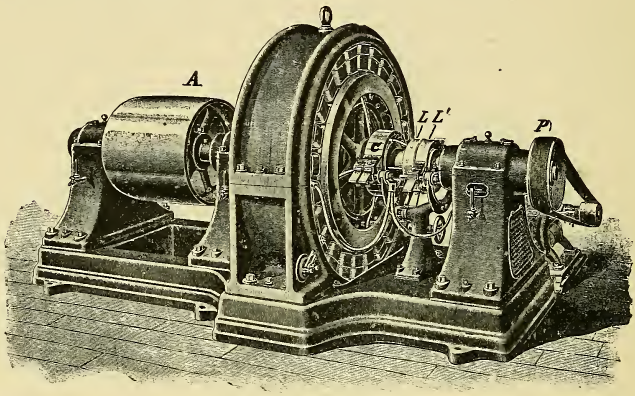


Fig. 125.

291. Fig. 125 represents a complete alternator, with its separate exciter, in the form of a small continuous current generator driven by a belt from the pulley P, on the alternator shaft. The main driving pulley is shown at A, the collector rings are shown at L L′, and the commutator at C.

292. Armature windings are either series or parallel-series. The series winding, shown in Fig. 126, has the disadvantage that the points of maximum electrical pressure are brought close together. On the other

hand the parallel-series winding, shown in Fig. 127, requires twice the number of turns to generate the same E. M. F., but has the points of maximum electrical pressure the greatest possible distance apart.

Alternator armatures are either ring-wound, drum-wound, disc-wound or pole-wound. In the United States, pole wound armatures, i. e., iron-clad armatures, are in most general favor, but in Europe disc-winding is more common.

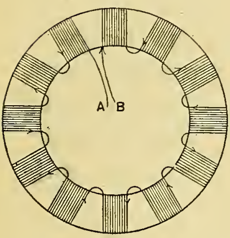
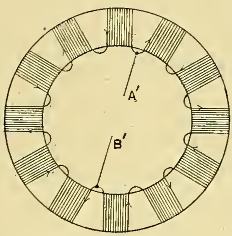
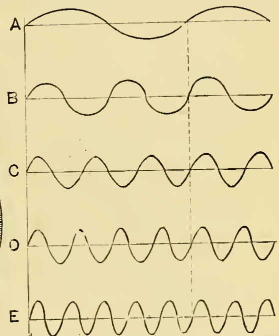


FIG. 126.



Elec. Engineer

FIG. 127.



Elec. Engineer

FIG. 128.

293. It is well to remember that the danger to life from a shock produced by a high electrical pressure is greater with an alternating than with a continuous current generator at the frequencies commercially employed. Experiments on animals have shown that the fatality of an alternating current pressure is approximately from two to three times that of the same pressure in continuous currents, the difference being apparently due entirely to physiological causes. At much higher frequencies it has been shown, that for physiological reasons not yet understood, alternating currents are less dangerous than continuous.

No matter how great the departure from the sinusoidal form of the E. M. F. wave produced by an alternator it can always be produced by a simple sinusoidal wave of the same frequency as the wave in question, compounded with a number of waves of frequencies 2, 3, 4, etc., times that of the fundamental. Thus an irregular wave having a frequency of 100 ~ can always be produced by a simple sinusoidal or fundamental wave of the type shown in Fig 128 A, and some combination of sinusoidal waves or *harmonics* of frequency 200 ~, 300 ~, 400 ~, etc., just as a wave in water, no matter how complex its form, can be made up of a simple wave of the full length, with successions of ripples of $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, $\frac{1}{5}$, etc., of this length, superposed upon its surface. In dealing with irregular, alternating-current waves it is sometimes convenient for purposes of calculation to assume that these irregular waves are such as could be produced by independent sinusoidal waves of definite frequencies that are subsequently united.

Fig. 128 shows at A a sinusoidal wave, and at B its first harmonic, there being two waves in B to each wave of A. At C is represented the second harmonic of A, since C possesses three waves to every wave of A; similarly D and E show the third and fourth harmonics of A respectively.

When, therefore, we speak of an alternating-current wave as having harmonics, we mean that its form is not simply sinusoidal, but requires to have some harmonic sinusoids added to some simple sinusoid in order to obtain the same wave form.

If an alternator with a frequency of 100 ~ producing such a sinusoidal E. M. F. of amplitude 800 volts,

($565\frac{6}{10}$ volts effective E. M. F.) is connected in series with a second sinusoidal alternator of 200 ~, which produces an E. M. F. of 400 volts amplitude ($282\frac{8}{10}$ volts effective E. M. F.), as shown in Fig. 129, as the first harmonic, then the total E. M. F. which will be generated by a combination of the two alternators, will

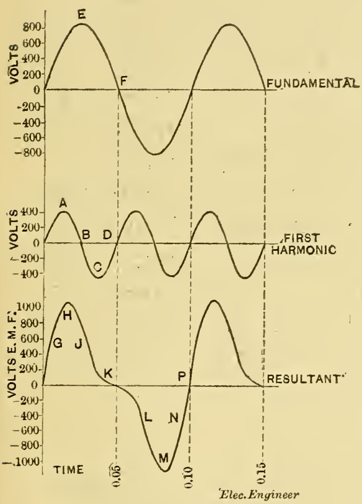


FIG. 129.

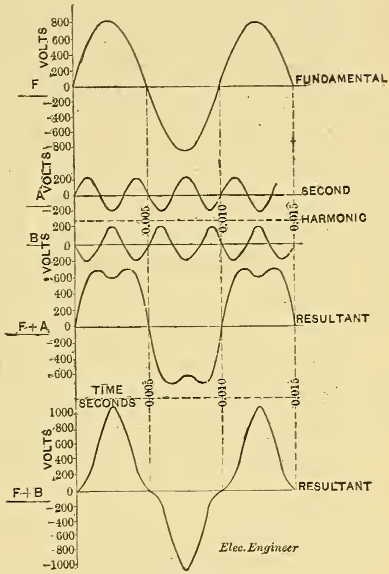


FIG. 130.

be the sum of the two independent E. M. F.'s at each instant. For example, at the point on the curve F, of the fundamental, the first harmonic is also on the zero line at D, and the sum of the E. M. F.'s will be zero, so that the resultant E. M. F. expressed by the curve O G H J K L M N P, is also zero at K. About the first $\frac{1}{8}$th period of the fundamental wave, in the ascent from O, to E, the

E. M. F. of the first harmonic is a maximum, namely, at A, and the sum of these two will reach its maximum at H. The resultant wave will, of course, repeat itself in each cycle.

At Fig. 130 is shown the effect of combining the second harmonic A, of the fundamental with a sinusoidal E. M. F. F, the resultant being shown at F + A, as a flattened wave. If, however, the second harmonic be displaced by one-half its own period, as at B, so that it starts off in the opposite direction to F, the sum of the two will be shown at F + B, which is a sharply peaked wave instead of a flattened wave. It is evident, therefore, that, when we are dealing with a flattened or a sharpened wave, we may sometimes find a second harmonic, which, united with a fundamental wave, will produce the wave under consideration as their resultant, and we may then imagine that instead of the actual alternators supplying a circuit we have two sinusoidal alternators in series, one having three times the frequency of the other. Such a conception is useful for simplifying calculations which may occur in dealing with alternating-current circuits.

Syllabus.

The number of poles in an alternator is determined by the frequency of the alternation and the speed of rotation.

Alternator armatures may be connected with their coils in series or in parallel-series.

Laboratory of Houston & Kennelly,
Philadelphia.

WEEKLY.

No. 34. FEBRUARY 2, 1895. Price, - 10 Cents. Subscription, $3.00.

Electrical Engineering Leaflets,

—BY—

Prof. E. J. Houston, Ph. D.

AND

A. E. Kennelly, F. R. A. S.

ELEMENTARY GRADE.

ALTERNATORS.

294. Since in an alternating current there are twice as many waves as periods per second, an incandescent lamp, operated at a frequency of 25 periods, will receive 50 current waves, and there will be 50 temperature fluctuations in its filament per second. This increase and decrease in the temperature of the filament produces an unsteadiness or flickering of the light, disagreeable to the eye. If the frequency be increased, the flickering becomes less marked, and practically disappears at about 30 $\sim$, the reason being that the difference in candle-power during each cycle becomes smaller, since the filament has less time to lose its heat, and these smaller fluctuations, succeeding each other with greater rapidity, the eye is unable to perceive them. The higher the efficiency, and the smaller and finer the filament, the higher will be the frequency required to suppress the fluctuations. The frequency at which alternators are ordinarily employed for incandescent lighting, in the United States, is from 125 to 133 $\sim$.

Published by
THE ELECTRICAL ENGINEER,
203 Broadway, New York, N. Y.

[Entered as second-class matter at the New York, N. Y., Post Office, June 14, 1894.]

295. Arc circuits are sometimes supplied by alternators. For such purposes alternators are required to maintain automatically constant the current strength in their circuits under all conditions of load. This is accomplished by so winding the armature that any excess in the current strength through it will demagnetize the field, and if, on the contrary, the current strength falls too low, the field magnets will be enabled to generate a

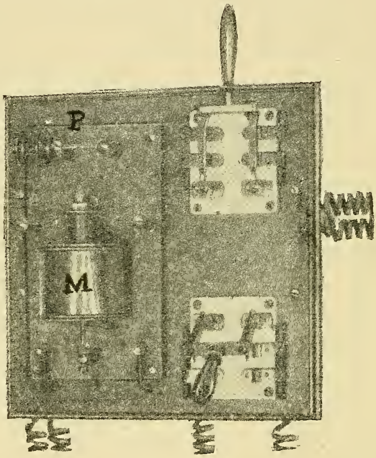


Fig. 131.
Short Circuiting Device for Arc Alternator.

higher E. M. F. On open circuit, the E. M. F. of the armature may be so high as endanger the insulation of the machine. To avoid this a device shown in Fig. 131 is employed. Two opposed points P, are separated at an adjustable distance in air, and so connected with the main terminals of the armature, that when the pressure rises to such an amount as will cause a spark discharge to take place across the points, the electromagnetic de-

vice M, placed in the circuit, immediately short-circuits the armature.

296. If two similar alternators be run together in the same circuit, one of them can be operated as a generator and the other as a motor, but these conditions can only be sustained so long as the two machines are in step. Machines running in step are said to run *synchronously*, so that an alternator can be driven as a *synchronous motor* from a similar alternator. Synchronous motors, however, will either not start from rest at all, or will start only at light torque (Sec. 111), whereas most motors in industrial use require to be started at full, or even more than full load torque.

On this account, synchronous motors have not, as yet, come into extensive commercial use. The only alternating current motors in extended use, which will start from rest with full torque, are called *induction motors*, and require the use of more than a single alternating current; that is, *multiphase currents.* Alternators for supplying such currents are called *multiphase alternators* or *multiphasers.* The three types of multiphasers in common use are *diphasers*, *triphasers*, and *monocyclic alternators.* A diphaser is an alternator supplying two diphase E. M. F.'s; that is, two separate E. M. F.'s of equal frequency and magnitude, but differing in phase by a quarter cycle, so that one lags behind the other 90°. These alternating E. M. F.'s are obtained by placing two windings on the armature, so arranged with relation to the field poles, that the E. M. F.'s in one series are generated $\frac{1}{4}$ of a cycle ahead of those in the other. Each of these two E. M. F.'s may be brought out to a pair of collector rings, as shown in Fig. 132. In which case

two separate circuits are provided, one for each current; or, the windings may be brought to three collector rings,

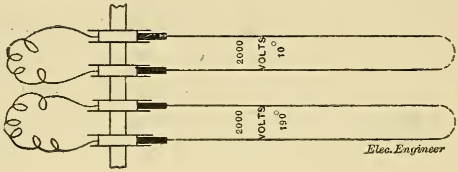


FIG. 132.
Diphase Connections, Separate Circuits.

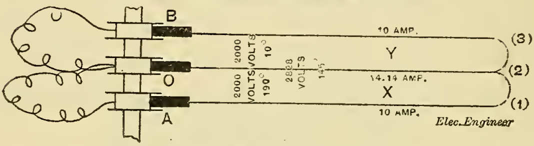


FIG. 133.
Diphase Connections, Interconnected Circuits.

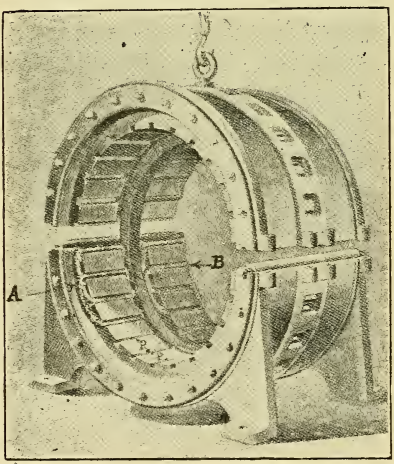


FIG. 134.
Diphase Armature Showing Coils.

as shown in Fig. 133, in which case the two circuits employ a common return conductor.

297. A particular form of diphaser is shown in Figs. 134 and 135. In this machine the armature is fixed, and the field revolves within it. The armature is wound with 48 coils, in two sets of 24 each. The two windings are seen to overlap each other by a quarter cycle, the frequency of the machine indicated being 133 ∼ in each circuit. The field magnet consists of a single large coil, embracing the frame shown in Fig. 135, whose polar projections N, and S, are north on one side and south on the other.

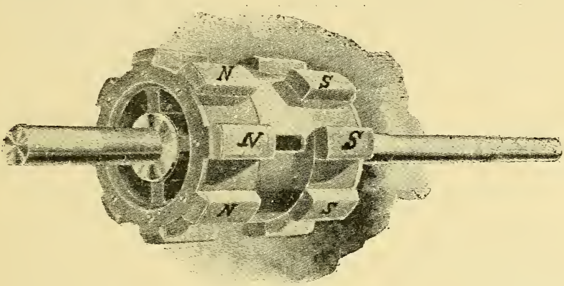


Fig. 135.
Diphase Revolving Field.

Fig. 136 is a diagram of two diphase E. M. F.'s, each 1100 volts, drawn to scale. When employing a common return wire, as shown in Fig. 133, the E. M. F. between the two external wires is represented by the length of the line A B, Fig. 136, or 1555 volts effective.

The currents in two diphase circuits are also in quadrature when the loads in the two circuits are the same.

298. A triphaser is an alternator supplying three separate E. M. F.'s separated by $\frac{1}{3}$ cycle, or 120°, as represented by Fig. 137 and 138. The armature coils are divided

into three parts, and the E.M.F.'s in these parts are arranged by suitably spacing the coils with reference to the poles of the field frame, so that the E. M. F.'s are separated by $\frac{1}{3}$ cycle. Thus O A, Fig. 137, is 120° behind O B, and O B, is 120° behind O C, while O C, is 120° behind O A. This winding is called the *star winding* because the three series are connected to a common point O, from which they may be considered to radiate. When the three windings are connected end to end, as in Fig. 138, the triphaser is said to have a *triangular winding*. The E. M. F. which is generated in a star winding is not measured

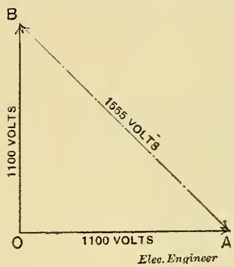


FIG. 136.
Diagram of Diphase E.M.F.'s.

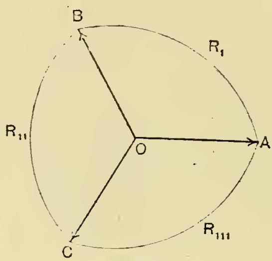


FIG. 137.
Star Triphase Winding.

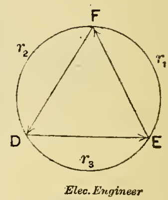


FIG. 138.
Triangle Triphase Winding.

from the common point of connection, but between one pair of outer terminals, such as A B, B C, or C A, Fig. 137, and by Fig. 139, it will be seen that the effective E. M. F. between such terminals is about 73 per cent. greater than between any one terminal and the common connection, so that when 1000 volts effective is generated in any particular winding, such as O C, the effective E. M. F. of the machine will be 1732 volts.

299. Since the object of a multiphase system is the operation of motors which will start from rest with full torque, and since such motors only constitute

a small fraction of the total load usually imposed on a central station, a combination has recently been effected of a uniphase and triphase system in what is called the *monocyclic system.* This system requires two conductors for all incandescent and arc lighting, or for synchronous motors, an additional wire called a *power wire* being specially run to such locations as may require a triphase motor to be operated.

The monocyclic alternator consists essentially of a uniphase alternator generating say 2000 volts, as represented by the line O A, Fig. 140. At the centre of the main winding a shorter and thinner winding is intro-

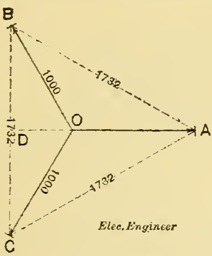


FIG. 139
Triphase E. M. F. Diagram.

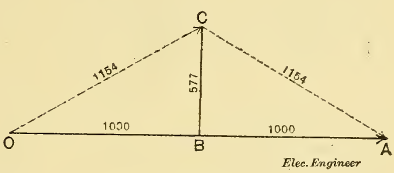


FIG. 140.
Monocyclic E. M. F. Diagram.

duced at B, and so arranged that its E. M. F. B C, of about 577 volts, is in quadrature with O A. The two extremities O, and A, are brought to two main collector rings, while the third winding has its extremity B, brought out to the third collector ring. Between the terminals O, and C, there will be an E. M. F., as shown by the dotted line, of 1154 volts, $\frac{1}{12}$ cycle or 30° ahead of the main E. M. F. O A, while between the pair of terminals C, and A, there will be a similar E. M. F. C A, 30° behind the main E. M. F. Wires from O, and A, are carried to the mains

over the system, and supply uniphase currents to synchronous motors, or to transformers for incandescent and arc lights. Where an induction motor is to be operated, a third wire is carried from the terminal C, and the two transformers installed, as shown at Fig. 141. The uniphase E. M. F. is not employed in this case, but the two E. M. F.'s O C, and C A, are connected, one to each transformer. The secondary E. M. F.'s, say each 100 volts effective, are represented diagrammetrically in Fig. 142 by O′ C′, and C′ A′, which are similar to the primary E. M. F.'s in phase difference, but reduced in magnitude.

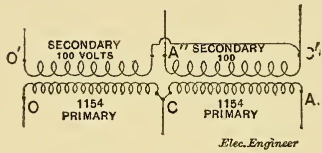


FIG. 141.
Monocyclic Triphase Transformer Connections.

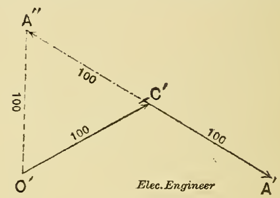


FIG. 142.
Combination of Secondary Manocyclic E.M.F. into Triphase System.

By reversing the E. M. F. C′ A′, that is, by reversing the secondary wires leading from the transformer, its direction is reversed, and the E. M. F. becomes C′ A″. This reversal of secondary connections is shown in Fig. 141. The three terminals O′ C′, and A″, have now between them three triphase E. M. F.'s, each of 100 volts as shown in Fig. 142 by the lines O′ C′, C′ A″, and A″ O′, the first two are supplied by the transformers separately, and the third by the combined connection of the two together, so that these terminals are attached to the main terminals of the triphase motor.

Laboratory of Houston & Kennelly,
Philadelphia.

WEEKLY.

No. 35. FEBRUARY 9, 1895. Price, - 10 Cents. Subscription, $3.00.

Electrical Engineering Leaflets,

—BY—

Prof. E. J. Houston, Ph. D.
AND
A. E. Kennelly, F. R. A. S.

ELEMENTARY GRADE.

Alternating Current Transformers.

---

300. When the area of distribution over which alternating current transmission extends exceeds certain limits, economy in the conducting circuit requires that the pressure of transmission should be high and the current strength correspondingly low, the product of the two, when in phase, being the activity transmitted expressed in watts. We have already seen (Sec. 258), that in a particular case of arc light distribution, the saving in copper effected by the use of a high pressure series circuit, reduced the expenditure in copper 2500 times, compared with a low-tension multiple circuit.

In actual practice, the high pressures employed in alternating-current distribution circuits are usually too high for the lamp, motor, or other apparatus, designed to be operated. In order, therefore, to combine the advantages of high pressure in transmission, with low-pressure in delivery circuits, contrivances called *transformers* are employed, whereby the high electromotive force is locally reduced to the desired pressure.

Published by
THE ELECTRICAL ENGINEER,
203 Broadway, New York, N. Y.

[Entered as second-class matter at the New York, N. Y., Post Office, June 14, 1894.]

301. When in the simple form of alternating-current transformer, illustrated in Fig. 49 (Sec. 135), a powerful alternating magnetic flux is sent through a secondary coil of wire by an alternating M. M. F. impressed by a neighboring or primary coil, as the secondary turns are filled and emptied with flux, electromotive forces are induced in them by an action which is called *mutual induction* (Sec. 161).

If the number of turns in the secondary coil is the same as the number of turns in the primary coil, the E. M. F. induced by the alternating magnetic flux will be the same in the secondary, as in the primary circuit, provided no magnetic leakage exists. If, however, the number of turns in the secondary is 10 times smaller than in the primary, the secondary E. M. F will be $\frac{1}{10}$ of the primary E. M. F. In such a case, in practice, the cross-section of the secondary wire is made, say, 10 times greater, so as to carry a current 10 times stronger than that in the primary circuit. Consequently, if the transformer receives 1 ampere at 1000 volts pressure at its primary terminals, and could have an efficiency of 100 per cent., it would deliver 10 amperes at 100 volts pressure, assuming the same power factor for both primary and secondary circuits. If in such an alternating-current transformer, a current of 10 amperes at 100 volts pressure were supplied to the short-wire coil, which would thus act as a primary, the long-wire coil would deliver 1 ampere at 1000 volts pressure as a secondary coil.

302. An alternating current transformer is, therefore, reversible. A transformer which lowers the pressure is called a *step-down transformer*; when it raises the pressure it is called a *step-up transformer*.

The simplest type of transformer is that shown in Fig. 143, where the ring core of iron wire, C C C, is wrapped with primary and secondary coils P, and S. When an alternating current circulates through P, an alternating M. M. F. is established in the magnetic circuit C C C, and the flux produced threads alternately in opposite directions through both coils. There is thus induced in each coil an E. M. F., which in the primary acts as a C. E. M. F., increasing the impedance of the primary coil and choking the primary current. The value of the E. M. F. in the secondary will, as already explained, depend upon the relative number of turns in the two coils.

303. If the secondary circuit be opened, so that the secondary E. M. F. can produce no current, and if there be no waste of energy by hysteresis or eddy currents in the core (Sec. 177), there will be no expenditure of energy in the transformer, except the heating of the primary coil by the primary current. In actual practice, not only is energy expended in heating the windings owing to the resistance offered to the primary and secondary currents, but the iron core is heated by hysteresis, and also by such *eddy currents* as may be formed in it. Eddy currents are secondary currents set up, not in a special winding but in a mass of metal, which may be accidentally traversed by a suitably directed, alternating magnetic flux. Eddy current losses can be reduced to an almost negligible minimum by a suitable lamination of the core in a direction parallel to the magnetic flux; that is, by dividing the mass of the core into a number of thin sheets so that the mass of iron, in which a small secondary circuit could be set up, is very greatly reduced and the resistance of such secondary circuits greatly increased.

The principal loss of energy in transformers is in hysteresis; for, at every reversal of magnetization some energy is expended in the iron core, and in 24 hours, a transformer operated at 139 ~, receives about 24 millions of reversals. The softest and best iron is, therefore, selected for the cores in order to reduce the hysteretic loss as much as possible.

304. There are various ways in which the primary and secondary coils can be linked with a magnetic circuit, such, for example, as those illustrated in Figs. 49, 50 and 51. The arrangement shown in Fig. 143 is now rarely employed in practice, owing to the large amount

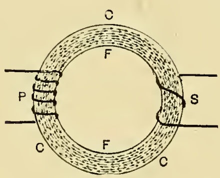


FIG. 143.

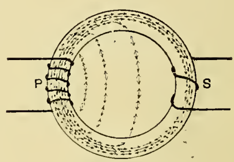


FIG. 144.

of magnetic leakage which would then take place between the primary and secondary coils, as illustrated diagrammatically in Fig. 144. Figs. 145, 146 and 147 represent other forms of alternating-current transformers in use, P P and S S, representing in each the primary and secondary terminals, respectively, when, as is usually the case, they are employed as step-down transformers.

305. In order to avoid dangers arising from accidental contact with primary circuit pressures which may be 1000, 2000 or 3000 volts effective, the transformer is generally placed outside the building it sup-

plies, as for example, in Fig. 148, where the transformer is shown mounted on a pole. The primary and secondary wires are led to a fuse box B, at the base of the transformer, and by pulling down the knob under this fuse box, all the connections of the two primary and two secondary wires can be simultaneously opened. V, is a ventilator for keeping the interior of the transformer case

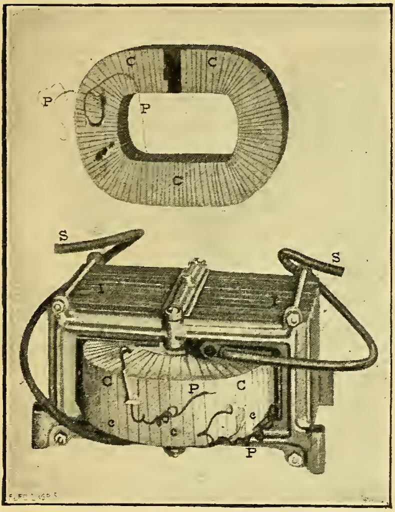


Fig. 145.

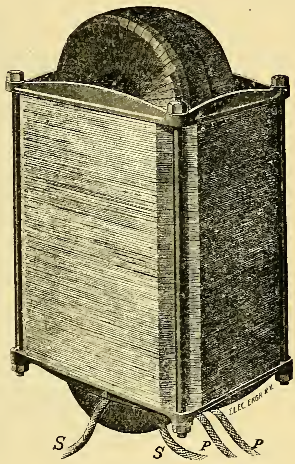


Fig. 146.

cool. Transformers should never exceed 50° C. in temperature elevation after prolonged full loads, and well designed transformers are usually limited to a rise of 40° C. above the temperature of surrounding objects.

In the transformer shown in Fig. 147, the iron surrounds the primary and secondary coils in the form of thin sheets or U-shaped stampings, alternately upwards

and downwards, instead of the coils surrounding the iron as in Fig. 144.

The best and softest iron, divided into sheets about $\frac{1}{70}$ inch thick, is employed for transformers. These sheets, when packed side by side, are insulated from one another by thin paper, varnish, or a superficial layer of iron oxide.

Safety fuses are always inserted in the primary, and

Fig. 147.

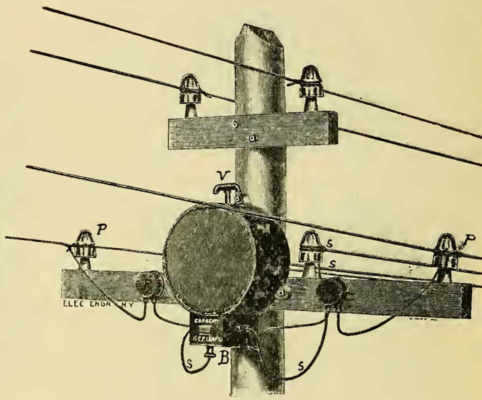


Fig. 148.

sometimes in the secondary circuits of a step-down transformer, in order to cut out the transformer in case of excessive current. See Fig. 149.

306. In the same transformer the efficiency increases with the load, and in different transformers with their size. Large transformers, of say 50 KW. capacity, usually have an efficiency of over 98 per cent. at full load and 95 per cent. at quarter load, while a small trans-

former of say 10 lights, or $\frac{1}{2}$ KW. capacity, would have, perhaps, only an efficiency of say 90 per cent. at full load, and 70 per cent. at quarter load. The efficiency of a transformer should be as high as possible, not merely at full load or half load, but at the average load which

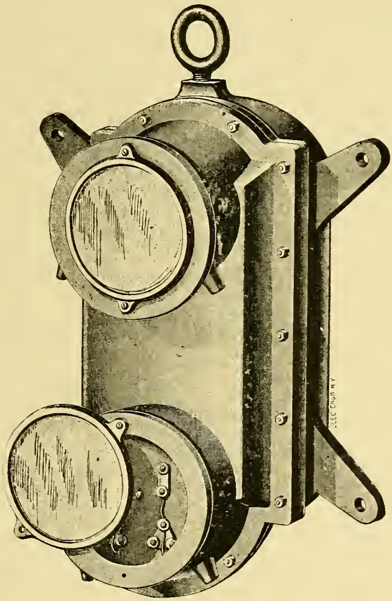


FIG. 149.

the transformer has to maintain ; for, a transformer which wasted much energy during 20 hours of no load, and then showed an efficiency of say 98 per cent. efficiency during the remaining four hours of full load, might be a less economical apparatus to operate, than one which wasted

a smaller quantity of activity during the 20 hours of no load, and had, say only 93 per cent. efficiency during the four hours of load.

307. The power factor of a transformer depends upon its size, its load and the nature of its load. A moderate-sized transformer at full load supplying incandescent lamps, i.e., a non-inductive load, will usually have a power factor of perhaps 99½ per cent.; but, if loaded with a motor, that is, an inductive load, its power factor may be, say, 90 per cent. The power factor of a transformer at no load is usually about 70 per cent.

Laboratory of Houston & Kennelly,
Philadelphia.

INDEX.

Action, Local, of Voltaic Cell.................... 69
Activity of Alternating Current Circuit, Determination of..........252, 253, 254
Adjustable Resistance 21
Adjustable Resistance, Diagram of Connections... 26
Aero-Ferric Magnetic Circuit, Definition of ...102, 103
Aero-Ferric Magnetic Circuit, Distribution of Reluctance in 107, 108
Air, Churning of, by Dynamo-Electric Machine.... 139
Air-Gap, Magnetic........ 103
All Night Lamp. 223
Alloys, Effect of Temperature on Resistance of ... 21
Alternating Arc Circuits... 266
Alternating Current... ... 236
Alternating-Current Circuit, Definition of Power Factor in 254
Alternating-Current Circuit, Skin Effect in........255, 256
Alternating-Current Circuits, Harmonics in 262
Alternating-Current Transformer............272 to 280
Alternating-Current Transformer, Definition of 273
Alternating Currents.. 233, 264
Alternating Currents, Dangers from........ 261
Alternating Currents, Definition of.... 45
Alternating E. M. F., rectangular wave type of ... 238
Alternation, Frequency of. 234
Alternations, Definition of. 233
Alternator, Armature Winding of.....,........... 260
Alternator, Definition of... 233
Alternators......... 257 to 264
Alternators, Commercial, Frequency of 265
Alternators, Monocyclic... 267
Alternators, Multiphase.... 267
Alternators, Series Connection of Armature of..257, 258
Amalgamation of Zinc in Voltaic Cell 69
Ammeter, Definition of.... 46
Ampere Hour, Definition of 45
Ampere, International, Definition of 44, 45
Ampere Meter, Definition of 46
Ampere-Turn, Definition of 95
Ampere-Turns, Dependence of M. M. F. upon..... 116
Arc Alternator, Short Circuiting Device for....... 266

Arc Lamp, Series-Connected.............224 to 227
Arc Lamp, for Incandescent Circuits..............227, 228
Arc Light, Circumstances Affecting steadiness of.. 221
Arc Light, Globes for..... 230
Arc Light, Mean Candle-Power of 220
Arc Light, Mean Spherical Candle-power of 220
Arc-Light Motors 191
Arc Light, Penetrating Power of 230
Arc Light Projector....230, 231
Arc Lighting.... ...216 to 232
Arc, Voltaic............... 217
Arc, Voltaic, Influence of length of, on Lighting Efficiency............... 218
Armature, Alternator, Varieties of Windings of.... 261
Armature, Diphase........ 268
Armature of Dynamo-Electric Machine, Definition of...................... 129
Armature of Dynamo, Mechanical Balance of...... 149
Armature of Motor, Continuous Current Type, Resistance of 185
Armature Winding of Alternators 260
Arms of Balance.......... 28
Arms of Bridge...... 28
Artificial Graphite on Arc Light Carbons 218
Artificial Resistance....... 22
Attractions and Repulsions of Currents 166
Attractive Magnets, Powerful Acting, ... 117
Attractive Magnets, Swift-Acting.................. 117
Attractive Power of Magnets 117
Automatic Regulation of Compound-Wound Generator 155, 156
Automatic Regulation of Shunt-Wound Generators 155, 156

Balance, Arms of 28
Balance, Wheatstone's..27, 28
Base of Lamp............. 201
Battery, Electric, Definition of 61
Battery Voltaic 85
Battery, Voltaic, Definition of......... 12
Battery Voltaic, Necessity for Insulating........... 85
Begohm, Definition of..... 31
Bicrohm, Definition of. .. 30
Bichromate Voltaic Cell.73, 74
Binding Posts for Voltaic Cells 86, 87, 88
Blackening of Lamp Chamber...... 205
Block, Fuse........ 197
Boxes, Junction........... 38
Bridge, Arms of........... 28
Bridge, Wheatstone's...27, 28
Broken or Open Circuit.... 10
Brushes, Carbon, of Dynamo-Electric Machine 151
Brushes, Lead of.......... 148
Brushes, Operation of..... 150
Building-up of Generator . 158

Bus Bar, Definition of..... 157

Cable, Object of Lead Covering ... 38
Cable, Sheathing of 38
Callaud Voltaic Cell .. 76, 77
Candles, Jablochkoff...... 223
Candle-Power of Arc Light-Mean.................. 220
Candle-Power of Incandescent Lamp 219
Candle, Standard......204, 205
Candle-Foot, Definition of. 209
Capacity, Safe Carrying, of Conductor........ 195, 196
Carbon Brushes of Dynamo-Electric Machine........ 151
Carbon, Effect of Temperature on Resistance of .. 20
Carbon Electrodes for Arc Lamps, Manufacture of.. 221
Carbon Electrodes for Arc Lamps, Size of.......... 223
Carbon Electrodes of Arc Lamps, Electro-Plating of 222
Carbon Electrodes of Arc Lamps, Life of.....222, 223
Carbon Rheostat.......... 27
Carbons, Cored............ 221
Carbons, Coreless.......... 221
Cell, Porous, of Voltaic Cell 75
Cell, Voltaic 11
Cell, Voltaic..........65 to 88
Cell, Voltaic, Approximate Cost of Electrical Energy in 68
Cell, Voltaic, Bichromate 73, 74
Cell, Voltaic, Callaud...76, 77
Cell, Voltaic, Connections of 78
Cell, Voltaic, Connectors for..................... 86
Cell, Voltaic, Daniell...74, 75
Cell, Voltaic, Definition of negative plate of 68
Cell, Voltaic, Definition of positive plate of 68
Cell, Voltaic, Edison-Lalande 78
Cell, Voltaic, Fuller....... 77
Cell, Voltaic, Gravity...76, 77
Cell, Voltaic, Leclanché... 78
Cell, Voltaic, Local Action of 69
Cell, Voltaic, Methods of Avoiding Polarization in. 70
Cell, Voltaic, Single-Fluid. 71
Cell, Voltaic, Solid Depolarizer Type of............ 77
Cell, Voltaic, Source of Energy of 68
C. E. M. F., Definition of.... 170
C. E. M. F. of Polarization.. 70
Charge, Electric........... 2
Choking Coil.............. 246
Circuit, Constant-Current. 60
Circuit, Impedance of..... 244
Circuit, Inductance of...... 127
Circuit, Inductive, Alternating-Current 250
Circuit, Magnetic.......... 91
Circuit, Magnetic, Electric Analogue of. 109
Circuit Magnetic, Law of.. 105, 106
Circuit, Metallic, Definition of 33, 34
Circuit, Multiple, Definition of............. 61

Circuit, Multiple-Series, Definition of 63
Circuit, Non Inductive, Alternating-Current........ 251
Circuit, Open or Broken . 10
Circuit, Parallel, Definition of 61
Circuit, Series-Multiple, Definition of.............. 63
Circuit, Telegraphic, Representation of Leakage in 53
Circuit, Twin-Wire........ 251
Circuits, Alternating Arc.. 266
Circuits, Electric... 57, 64
Circuits of Magnetic and Electric Flux, Difference Between . .. .97, 98
Circuits, Series, Definition of 59
Circular, Flux-Paths Around Conductor Conveying Current......... 114
Classification of Receptive Devices................. 59
Closed-Circuit Type of Voltaic Cell..............81, 82
Coil, Choking... 246
Coil, Primary............. 127
Coil, Secondary........... 127
Coils, Conducting, Effect of Magnetic Flux on........ 163
Common Stock of Work... 6
Commutator of Dynamo-Electric machine, Definition of 130
Commutator, Operation of, 150
Compound-Wound Generator..................... 156
Condenser, capacity of..... 244
Condenser, Description of.. 244
Conductor, Electric........ 22
Conductor, Electric. Effect of Character of Material upon Resistance of 18
Conductor, Electric Effect of Cross Sectional Area upon Resistance of 18
Conductor, Electric, Effect of Length upon Resistance of. 18
Conductor, Electric, Effect of Physical Conditions of Resistance of........... 20
Conductor, Electric, Effect of Temperature on Resistance of............. 20
Conductor, Electric, Rise of Temperature in 194
Conductor, Purity of, Effect of on Resistance of.. 20
Conductor, Resistance of, to Electric Flow......... 17
Conductors, Resistance Table of................ 35
Conductor, Ribbon........ 39
Conductor, Safe Carrying Capacity of.........195, 196
Conductor, Stranded . . 39
Conduits, Electric.... 38
Conduits, Manholes in..... 38
Connections, Monocyclic, Triphase Transformer... 272
Connections of Voltaic Cell, 79
Connectors for Voltaic Cells 86, 87
Constancy of Energy in Universe................ 7
Constant Current Circuit .. 60
Continuous Current, Definition of................. 45

Continuous-Current Electric Motor, Advantages of over Steam Engine.. 185
Continuous Multiple Incandescent Lighting Generators.................... 154
Convention as to Direction of Magnetic Flux. .. 90, 91
Copper Wires, Table of Resistance of... 35
Core, Laminated, Construction of 140
Cored Carbons 221
Coreless Carbons.... 221
Coulomb, Electrolytic Effect of 44
Coulomb, Definition of 43, 44
Coulomb, International Definition of... ..... 43 44
Counter-Electromotive Force of Motor 170
Counter-Electromotive Force of Motor, Value of, 174
Counter-Electromotive Force of Motor, Variation of, with load 173
Counter-Electromotive Force of Self-Induction, Effective Frequency of Alternation of. 251
Couple, Copper-Zinc 66
Couple, Voltaic, Definition of................ 66
Crater, Arc, Influence of Size of on Light Emitted, 219
Crater in Positive Carbon, 217
Creeping of Electrolyte in Voltaic Cell 84
Current, Alternating...... 236
Current, Electric 2
Current, Electric .... 41 to 48
Current, Electric, Direction of Flux Produced by.... 114
Current, Periodic, Alternating Rectangular Type . 236
Currents, Alternating, Definition of................ 45
Currents, Continuous, Definition of................ 45
Currents, Local Eddy, of Dynamo-Electric Machine...... 140
Currents, Multiphase, Definition of................ 267
Currents, Mutual Attractions and repulsions Produced by................ 166
Currents, Pulsatory, Definition of....... 45
Cut-Out, Film, of Series Incandescent Lamp........ 212
Cycle, Definition of 234
Cymogene and Rhigolene, use of, in Flashing Process.... 203

Danger to Life from Electric Discharge 13, 14
Daniell Voltaic Cell ...74, 75
Depolarizers 71
Depolarizer, Solid.... 77
Devices, Electro Receptive, Definition of 57
Devices, Translating, Classification of............. 59
Devices, Translating, Definition of 57
Diagram, Monocyclic E. M. F 271
Diagram, Triphase E. M F.'s, 271
Difference of Fluid Level . 49

Diphase, Armature 268
Diphase, Connections, Interconnected Circuits.. . 268
Diphase Connections, Separate Circuits...... 268
Diphase E. M. F.'s, Diagram of 270
Diphase, Field............ 269
Diphasers................. 267
Discharge, Electric........ 2
Discharge Electric, Danger from 13, 14
Discharge, Spark......... 13
Discharges, Electric, Effects produced by....... 3
Disintegration of Filament, 205
Distribution Circuit, Efficiency of delivery of. 227
Double-Carbon Arc Lamp, 223
Double-Fluid Voltaic cells, 71
Drop, Definition of........ 53
Drop, Determination of.... 54
Dry Voltaic Cell.......... 79
Dynamo and Motor, Reversibility of. 170, 171
Dynamo and Motor, Reversibility of............ 183
Dynamo and Motor, Tabular contrasts of 171
Dynamo Brushes, Sparking of 147, 148
Dynamo, Cause of Sparking at Brushes in. 148
Dynamo, Closeness of Regulation of 159
Dynamo, Output of....134, 135
Dynamo, Output of Limitations to.... ...... 145, 146
Dynamo, Permissible Temperature Elevation of.. . 146
Dynamo, Regulation of 153 to 160
Dynamo, Series-Arc Lighting.................... 154
Dynamo, the ....129 to 152
Dynamo-Electric Machine, 11
Dynamo-Electric Machine, Armature, Definition of.. 129
Dynamo-Electric Machine, Belt Driving of......149. 150
Dynamo-Electric Machine, Brush Friction in....... 139
Dynamo-Electric Machine, Cause of Heating in, 143, 144
Dynamo-Electric Machine, Commercial Efficiency of, 137, 138
Dynamo-Electric Machine Commutator, Definition of......... 130
Dynamo-Electric Machine, Definition of Field Magnet of.................. 130
Dynamo-Electric Machine, Direct Driving of....149, 150
Dynamo-Electric Machine, Losses in 138
Dynamo-Electric Machine, means for Dissipation of Heat of 147
Dynamo-Electric Machine, Mechanical Losses in.... 139
Dynamo-Electric Machine, Rule for Calculating Electromotive Force Generated in..............134, 135
Dynamo-Electric Machine, Sources of Loss in...138, 139

Earth of Circuit 34

Earth's Flux, Action of on Magnetic Needle 167
Eddy Current Losses in Transformer.... 275
Eddy Currents, Local, of Dynamo-Electric Machine 140
Edison Lalande Voltaic Cell.................... 78
Effective Strength of Sinusodial Current or E. M. F. 239
Effects, Electric.. ....1 to 8
Effects, Electrolytic, of Electric Discharges........ 3
Effects, Heating, of Electric Discharges........ 3
Effects, Luminous, of Electric Discharges........ 3
Effects, Magnetic, of Electric Discharges....... 3
Effects, Mechanical of Electric Discharges....... 3
Effects of Electric Current, 41
Effects, Physiological, of Electric Discharges. .. 3
Effects Produced by Electric Discharges 3
Efficiency, Commercial, of Dynamo Electric Machine.............. ...137, 138
Efficiency of Delivery in Distribution Circuit. .. 227
Efficency of Incandescent Lamps...........205 to 207
Efficiency of Transformer, . 278, 279
Electric Analogue of Magnetic Circuit............. 109
Electric and Magnetic Flux, Difference Between Circuits of...............97, 98
Electric Circuits........57, 64
Electric Charge........... 2
Electric Conduits.......... 38
Electric Current........... 2
Electric Current.......41 to 48
Electric Current, Effects of 41
Electric Current, Work Done by............. ... 6
Electric Discharge 2
Electric Discharges, Effects Produced by 3
Electric Flow, Effect of Electic Pressure on....... 49
Electric Flow, Effect of Resistance on.......... 49
Electric Flow, Analogue of 43, 44
Electric Flow, Unit Rate of....................44, 45
Electric Heater........198, 199
Electric Heating.....193 to 200
Electric Pressure.......... 10
Electric Kettle............ 199
Electric Locomotive Headlight 230
Electric Motor, Continuous-Current Type, Methods of Altering Speed of..... 177
Electric Motor, Continuous-Current Type of...169 to 193
Electric Oven 200
Electric Resistance... 17 to 40
Electric Source, Definition of.... 10
Electric Sources, Classification of.................. 11
Electric Sources, Series Conection of....... 61
Electric Street-Car Heater, 199

Electrical Effects........1, 8
Electrification by Friction, 1
Electrodynamic Force. ... 161
Electrodynamic Force, Continuous Rotation by 165, 166
Electrodynamics.... 161 to 168
Electrolyte, Creeping of, in Voltaic Cell............. 84
Electrolyte, Definition of.. 66
Electrolytic Effects of Electric Discharges........ 3
Electro-Plating of Arc Lamp Electrodes....... 222
E. M. F., Definition of...... 10
E. M. F., Dynamo-Electric Generation of in Conducting Loop ..131, 132, 133, 134
E. M. F., Fluctuating...235, 236
E. M. F., Methods of Increasing.................... 15
E. M. F., of Cell, Independent of size of 79
E. M. F., Phase of 241
E.M. F., Pulsatory..... 235, 236
E. M. F., Total Effective.... 55
E. M. F.'s, Induced. 121
Electromagnet, Definition of..................... 113
Electromagnet............. 113
Electromotive Force...9 to 16
Electromotive Force, Definition of............... 9
Electromotive Force of Dynamo Armature, Circumstances Determining value of................ 134
Electromotive Force, Rectangular Type of Periodic Alternating. 236
Electromotive Force, Rule for Calculating Value of, Generated in Dynamo, 134, 135
Electro-Receptive Device, Definition of........ ... 57
Element, Voltaic, Definition of.................. 66
Energy, Constancy of, in Universe................ 7
Equalizer Feeder for Incandescent Light Circuits.................... 215

Feeder, Equalizer, for Incandescent Lamp Circuits.............. 215
Feeder, Equalizer Switch, 215
Feeders for Incandescent Light Circuits.... 215
Ferric-Magnetic Circuit, Definition of............ 102
Field, Diphase............ 269
Field Magnet of Dynamo-Electric Machine, Definition of.................. 130
Field Magnetic............ 89
Field Magnetic, Delineation of 90
Film Cut-out of Series Incandescent Lamp....... 212
Filament, Disintegration of, 205
Filament of Incandescent Lamp, Carbonizing Process for............. ... 202
Filament of Incandescent Lamp........ 201
Fixed or Constant Resistance 21
Flashing Process......... 203

Flow Electric, Effect of Electric Pressure on 49
Flow, Electric, Effect of Resistance on..... . .. 49
Flow Electric, Unit of...43, 44
Flow, Liquid, Effect of Area of Orifice on...... 49
Flow Liquids, Influence of Length of Armature upon........ 18
Flow of Liquids, Laws of.. 17
Fluctuating E. M. F 235, 236
Flux, Leakage. 108
Flux, Magnetic ... .105 to 112
Flux, Magnetic, Convention as to Direction of, 90, 91
Flux, Magnetic, Direction of, Produced by Current, 114
Flux, Magnetic, Methods of Increasing in Circuit .. 111
Fluxes, Soldering......... 30
Flux-Paths, Distribution, of 98
Flux Paths, Magnetic..90, 91
Flux, Uniform, Magnetic Effect on Conducting Loop, 162
Force, Electrodynamic ... 161
Force, Electromotive...... 9
Force, Electromotive, Induced............121 to 128
Force, Magneto-Dynamic.. 167
Frequency of Alternation . 234
Frequency of Alternation, Effective of Counter Electromotive Force of Self Induction............... 251
Frequency of Commercial Alternators............. 265
Friction, Brush, in Dynamo-Electric Machine 139
Frictional Electric Machine, 11
Friction, Electrification by, 1
Friction, Journal. 139
Fuse Block... 197
Fuse Strip....... 198
Fuses, Safety.. .....196 to 198
Fusewire.............. ... 197

Galvanometer, D'Arsonval, 47
Galvanometer, Definition of 46
Galvanoscope, Definition of 46
Gases, Comparative Resistance of...... . ...22, 23
Generator, Building Up of, 158
Generator, Compound-Wound.... 156
Generator, Over-Compounding of 157
Generator, Series-Wound, 154
Generator, Shunt-Wound, 154
Generators, Continuous-Multiple-Incandescent Lighting 154
Generators, Multiple Connection of 150
Gilbert, Definition of...... 95
Globes, Arc Light. 230
Graphite, Artificial, Arc Light Carbons 218
Gravity Voltaic Cell....76, 77
Grenêt Voltaic Cell, ...73, 74
Ground of Circuit 34

Harmonics in Alternating-Current Circuits......... 262
Head of Water. 49
Heater, Electric.......198, 199
Heating Effect of Electric Discharges...... 3
Heating of Dynamo, Cause Producing...........143, 144

Helix, Left-Handed, Polarity of.... 116
Helix, Polarity of, Rule for Determining.... 117
Helix, Right-Handed, Polarity of 116
Hood, for Arc Lamp...... 223
Hour, Ampere, Definition of 45
Hysteresis Loss in Transformer................. 276
Hysteresis, of Dynamo, Circumstances Affecting.....142
Hysteresis, Source of Loss in Dynamo-Electric Machines ....139 to 141

Illumination, Definition of 209
Illumination of Room, Effect of Character of Walls and Ceilings on........ . 210
Impedance and Resistance, Difference Between in a Circuit................... 249
Impedance, Definition of, 244
Impedance of Circuit...... 244
Incandescant Circuit, Arc Lamps for. 227, 228
Incandescent Light Cir-Circuits, Feeders for.... 215
Incandescent Lighting, 200 to 216
Incandescent Lighting, Advantages of as an Artificial Illuminant. 210
Induced E. M. F........121 to 138
Induced E. M. F., Circumcumstances Determining the Intensity of......122, 123
Induced E. M. F., Rule for Determining Direction of, 124, 125
Induced E. M. F.'s.......... 121
Inductance, Definition of.. 127
Inductance, Mutual 127
Inductance of Circuit...... 127
Induction, Dynamo-Electric, of E. M. F. in Conducting Loop .....131 to 134
Induction, Magneto-Electric........... 122
Induction Motor,.......... 267
Inductionless Resistance .. 244
Inductive Alternating-Current Circuit. 250
Insulators, Effect of Temperature on Resistance of, 22
Insulation Resistance..... 39
Insulators, Definition of... 22
Insulators, Telegraphic, 36, 37
Insulators, Telegraphic, Resistance of.............. 36
Intake, Definiton of 8
International Ampere, Definition of............44, 45
International Coulomb, Definition of......... .. 43, 44
International Ohm, Definition of.......... 18
Iron-Clad Magnet,........ 119
Iron-Magnetic Circuit, Definition of 102
Iron Wire, Resistance of Table,............... .. 35

Jablochkoff Candle........ 223
Joint Impedance, Determination of,................ 252

Joint, Magnetic, Reluctance of ... 111
Joint, Telegraphic, American Twist ... 29
Joint, Telegraphic, British. 29
Joint, Telegraphic, Butt .. 29
Joint, Telegraphic, McIntyre Sleeve ... 29
Joint, Telegraphic, Scarf . 29
Joint, Telegraphic, Western Union ... 29
Joints, Soldering of ... 30
Joints, Telegraphic, Bell-Hanger's ... 29
Joints, Telegraphic, Varieties of ... 29
Jump Discharge ... 13
Junction Boxes ... 38

Keeper of Magnet ... 120
Kelvin Balance-Ammeter, 110, 111
Kettle, Electric ... 199

Laminated Core, Construction of ... 140
Lamination of Core of Transformer ... 275
Lamp, All-Night ... 223
Lamp Base ... 201
Lamp Chamber, Blackening of ... 205
Lamp Chamber, Opacity of 207
Lamp, Double Carbon ... 223
Lamp, Efficiency of 205, 206, 207
Lamp Filament ... 201
Lamp Filament, Carbonizing Process for ... 202
Lamp, Multiple-Filament .. 211
Lamp-Socket ... 202
Lamps, Miniature Electric 207
Lamps, Multiple Incandescent ... 211
Law, Fundamental, of Magnetic Attraction ... 118
Law of Magnetic Circuit, 105, 106
Law, Ohm's, Symbolic Representation of ... 50
Leakage, Magnetic, Flux-Paths ... 95
Laws of Flow or Discharge of Liquids ... 17
Leading-in Wires ... 201
Lead Covering of Cable ... 38
Lead of Brushes ... 148
Leakage Flux ... 108
Leakage, Magnetic ... 108
Leakage, Magnetic, Effect of Magnetic Circuit, 100, 101
Leakage of Telegraphic Circuits ... 36, 37
Leakage-Paths, Magnetic. 95
Length and Diameter of Pipe, Influence of Liquid Flow ... 18
Life of Carbon Electrodes for Arc Lamps ... 223
Lighting, Incandescent, 200 to 216
Liquid Flow, Effect of Area of Orifice on ... 49
Liquid Flow, Effect of Head of ... 49
Liquids, Comparative Resistance of ... 22
Local Action of Voltaic Cell 69
Locomotive, Electric, Mining ... 190

Locomotive Headlight, Electric 230
Loop, Conducting, Circumstances determining, Direction of Induced E. M. F. in .... .124, 125
Loop, Conducting, Dynamo-Electric, Generation of E. M. F. in 131, 132, 133, 134
Loop, Rectangular, Effect of Uniform Magnetic Flux on..... 162
Losses, Electrical, of Dynamo Electric Machine.. 138
Losses, Hysteretic, Circumstances Varying Value of 142
Losses, Mechanical, of Dynamo-Electric Machine, 138, 139
Luminous Effects of Electric Discharges 3

Machine, Dynamo-Electric, Definition of Armature of 129
Machine, Dynamo Electric, Definition of Commutator of 130
Machine, Dynamo-Electric, Definition of field magnet of 130
Machine, Frictional Electric 11
Magnet, Iron-Clad........ 119
Magnet, Keeper of........ 120
Magnet, Multipolar........ 119
Magnet, Permanent....... 93
Magnet, Permanent, Definition of.... 113
Magnet, Zig-zag 119
Magnets, Attractive, Power of 117
Magnets, Portative, Definition of 117
Magnets, Tractive, Definition of 117
Magnetic Air-Gap 103
Magnetic and Electric Flux, Differences Between 92
Magnetic Attraction, Fundamental Law of........ 118
Magnetic Circuit.......... 91
Magnetic Circuit, Aero-Ferric Circuit, Definition of, 102, 103
Magnetic Circuit, Compound 102
Magnetic Circuit, Electric Analogue of 109
Magnetic Circuit, Ferric, Definition of............ 102
Magnetic Circuit, Law of 105, 106
Magnetic Effects of Electric Discharges............ .. 3
Magnetic Field............ 89
Magnetic Field, Delineation of 90
Magnetic Flux ......105 to 112
Magnetic Flux, Convention as to Direction of.....90, 91
Magnetic Flux-Density, Effect of on Reluctance.... 104
Magnetic Flux-Paths.. 90, 91
Magnetic Joint, Reluctance of 111
Magnetic Leakage 108
Magnetic Leakage-Paths.. 95
Magnetic Needle, Influence of Deflecting Flux on.... 163

Magnetic Pole, Positive, Definition of............ 91
Magnetic Reluctance 97 to 104
Magnetic Reluctance, Definition of................ 97
Magnetic Reluctance, Law of...................... 99
Magnetic Saturation....... 104
Magnetic Streamings 90
Magneto-Dynamic Force .. 167
Magneto-Electric Induction 122
Magnetomotive Force .89, 96
Magnetomotive Force, How Produced........ 93
Magnetomotive Force, Produced by Magnetic Source 92
Mean Candle-Power of Arc Light 220
Mean Spherical Candle-Power of Arc Light.... . 220
Mechanical Effects of Electrical Discharges 3
Mechanical Losses of Dynamo-Electric Machine .. 138
Megohm, Definition of 31
Methods of Increasing E. M F. 17
Microhm, Definition of.... 30
Miniature Electric Lamps. 207
Mining Locomotive, Electric...................... 190
M. M. F..... ....93, 95
M. M. F., Dependence of upon Ampere-Turns..... 116
M. M. F., Dependent upon Current Strength in Conductor................. 115
Monocyclic Alternators... 267
Monocyclic E. M. F., Diagram of................. 271
Monocyclic System ...271, 272
Monocyclic System, Power Wire of 271
Monocyclic, Triphase Transformer Connection 272
Motor, Armature, Continuous-Current Type, Resistance of..... 185
Motor, Continuous-Current, Starting Resistance of... 186
Motor, Counter-Electromotive Force of......170 to 173
Motor, Electric, Continuous-Current Type, Methods for Varying Speed of ... 177
Motor, Electric Continuous-Current Type of...169 to 193
Motor, Electric, Source of Driving Energy of 171
Motor, Induction 267
Motor, Shunt Wound, Regulation of under constant torque 179
Motor, Synchronous 267
Motor Torque, Definition of 174
Motors, Arc-Light 191
Multiphase Alternators.... 267
Multiphase Currents, Definition of 267
Multiphasers.............. 267
Multiple Circuit, Definition of 61
Multiple-Connected Incandescent Lamps 211
Multiple Connection of Generators................. 150
Multiple Filament Lamp .. 211
Multiple-Series Circuit, Definition of..... 63
Multipolar Magnet........ 119

Mutual Inductance.........127

Needle, Magnetic, Action of Earth's Flux on....... 167
Needle, Magnetic, Oscillations of 89
Negative Carbon, Nipple on 218
Negative Magnetic Pole... 91
Negative Plate of Voltaic Cell, Definition of 68
Negative Pole of Electric Source... 33
Negative Pole of Magnet.. 91
Nipple on Negative Carbon 218
Non-Conductor, Definition of 22
Non-Inductive Alternating-Current Circuit 251

Oersted, Definition of ... 103
Ohm, International, Definition of 18
Ohm, Standard, Description of................. 23
Ohm's Law............49 to 56
Ohm's Law, Symbolic representation of.......... 50
Open-Circuit Type of Voltaic Cell 81
Oscillations of Magnetic Needle..... 89
Output, Definition of...... 8
Output of Dynamo....134, 135
Output of Dynamo, Limitations to..............145, 146
Oven, Electric 200
Over-Compounding of Generator 157

Pair, Voltaic, Definition of 66
Parallel Circuit, Definition of 61
Parallel Connection of hand-regulated Shunt-Wound generators........... .. 156
Penetrating Power of Arc Light.................. 230
Permanent Magnet........ 93
Permanent Magnet, Definition of.................. 113
Phase of E. M. F. 241
Physiological Effects of Electric Discharges....... 3
Pipe, Influence of Smoothness of Walls of, upon Liquid Flow 18
Pipe or Conduit, Resistance of, to Liquid Flow....... 17
Platinum Leading-in Wires 201
Platinum Silver Alloy, Use of in Resistance......... 24
Plugs, Electric............ 28
Polarity of Left-Handed Helix... 116
Polarity of Right-Handed Helix................. . 116
Polarization of Voltaic Cell 70
Polarization of Voltaic Cell, Counter E. M. F. Produced by.. 70
Polarization of Voltaic Cell, Methods of Avoiding.... 70
Pole, Magnetic, North 91
Pole, Magnetic, North-Seeking, Definition of 91
Pole, Magnetic, South..... 91
Pole, Magnetic, South-Seeking................ .. 91
Pole, Positive, Definition of 91

Poles of Magnet, Definition of... 91
Poles, Telegraphic..... 36, 37
Portative Magnets, Definition of...... 117
Portative Magnets, Power of 117
Positive Carbon, Crater in 217
Positive Plate of Voltaic Cell, Definition of....... 68
Positive Pole of Electric Source 33
Power, Attractive, of Magnets 117
Power Factor of Alternating Current Circuit, Definition of............... 254
Power Factor of Transformer 280
Power of Portative Magnets 117
Power Wire of Monocyclic System 271
Pressure, Electric..... ... 10
Primary Coil 127
Process, Carbonizing, for Lamp Filament......... 202
Process, Flashing, ... 203
Projector, Arc Light...230, 231
Pulsatory Currents, Definition of 45
Pulsatory E. M. F. 235, 236
Pulsatory E. M. F., or Current, Graphical Representation of................ 235

Quadrature, Definition of.. 253

Rectangular Type of Periodic, Alternating Current 236
Rectangular Wave Type of Alternating E. M. F 238
Regulation, Automatic, of Compound-Wound Generator...............155, 156
Regulation, Automatic, of Shunt-Wound Dynamo, . 155, 156
Regulation of Dynamo, 153 to 160
Regulation of Dynamo, Closeness of 159
Regulation of Speed of Series-Wound Motor, 180, 181
Reluctance, Magnetic, Definition of.......... 97
Reluctance, Magnetic, Effect of Flux-Density on.... 104
Reluctance, Magnetic, Effect of Leakage on .100, 101
Reluctance, Magnetic, Law of.... 99
Reluctance, Unit of 103
Resistance, Adjustable.... 21
Resistance, Artificial 22
Resistance, Effect of Physical Condition of Conductor on 20
Resistance, Effect of Purity of Conductor on 20
Resistance, Electric.....17, 40
Resistance, Electric, of Pure Water 25
Resistance, Electric, Temperature Effect on 20
Resistance, Fixed or Constant 21
Resistance, Inductionless.. 244
Resistance, Insulation..... 39

Resistance of Armature of Continuous-Current Motor 185
Resistance of Carbon, Effect of Temperature on.. 20
Resistance of Conductors, Table of 35
Resistance of Conductor to Electric Flow.. 17
Resistance of Insulators, Effect of Temperature on 22
Resistance of Receptive Devices, Table of 40
Resistance of Telegraphic Insulators............ ... 36
Reversibility of Dynamo and Motor . ..170, 171, 183
Rheostat, Carbon 27
Rheostat, Definition of.... 21
Rheostat, Street-Car 188
Rhigolene and Cymogene, Use of, in Flashing Process 203
Ribbon Conductor 39
Rotation, Continuous, by Electrodynamic Force, 165, 166
Rule for Determining Electromotive Force Generated in Dynamo.....134, 135

Safety Fuse of Transformer Circuits 278
Safety Fuses,.....196, 197, 198
Saturation, Magnetic...... 104
Saturation, Magnetic, of Soft Iron 118
Secondary Coil............ 127
Series Arc Lighting Dynamos 154
Series Armature, Connection of, for Alternators 257, 258
Series Circuits, Definition of 59
Series-Connected Arc Lamps............224 to 227
Series Incandescent Lamp, Film Cut-Out of 212
Series Motor Under Constant Potential, Means for Regulation of........... 180
Series-Multiple Circuit, Definition of..... 63
Series-Wound Generator .. 154
Series-Wound Motor, Method of Regulating Speed of 180, 181
Sheathing of Cable 38
Short Circuiting Device for Arc Alternator 66
Shunt-Wound Generator... 154
Shunt-Wound Generator, Connections of 154, 155
Shunt-Wound Motor, Regulation of, under Constant Torque 179
Silver Chloride Voltaic Cell 78
Single-Fluid Voltaic Cells, 73, 71
Sinusoidal Wave, Definition of 236, 237
Skin Effect in Alternating-Current Circuit..... 255, 256
Socket, Lamp 202
Soft Iron, Magnetic Saturation of.................. 118
Soldering Fluxes.......... 30
Solid Depolarizers 77
Solids, Comparative Resistance of 22, 23

Source, Electric, Definition of ... 10
Source, Electric, Positive Pole of ... 33
Source, Magnetic ... 92
Sources, Connection of, in Parallel ... 62
Sources, Electric, Classification of ... 11
Sources, Electric, Production of E. M. F., by ... 57
Sources, Electric, Series Connection of ... 61
South Magnetic Pole ... 91
South-Seeking Magnetic Pole ... 91
Spark Discharge ... 13
Sparking of Dynamo Brushes ... 147, 148
Sparking of Dynamo, Cause of ... 148
Speed of Continuous-Current Motor, Methods for Producing Variations of. 177
Standard Candle ... 204, 205
Standard Ohm, Description of. ... 23
Star Triphase Windings... 270
Starting Box for Constant-Current Motor ... 187
Starting Resistance of Continuous-Current Motor, 186, 187
Steadiness of Arc Light, Circumstances Affecting. 221
Step-Down Transformer, Definition of ... 274
Step-Up Transformer, Definition of ... 274
Stranded Conductor ... 39
Streaming, Magnetic ... 90
Street-Car Heater, Electric 99
Street-Car Rheostat ... 188
Strength, effective of Sinusoidal Current or E. M. F. 239
Strip, Fuse ... 198
Switch, Feeder equalizer 215
Switch, Reversing for Motor 189
Synchronous Motor ... 267
System, Monocyclic ... 271, 272
System, Three-Wire, Defition of ... 64
System, Three-Wire for Incandescent Lamps...214, 215

Table of Receptive Devices 34
Table of Resistance and Diameter of Conductors. 35
Telegraphic Circuit, Representations of Leakage in. 53
Telegraphic Circuits, Leakage of ... 36, 37
Telegraphic Insulators..36, 37
Telegraphic Poles ... 36, 37
Temperature, Effect of on Resistance of Alloys ... 21
Temperature, Effect of on Resistance of Insulators. 22
Temperature Elevation, Permissible, in Dynamo. 146
Temperature Rise in Conductor ... 194
Temperature, Rise in Transformers, Limitations of.. 277
Thermo-Pile, Definition of 13
Three-Wire System, Definition of ... 64
Three-Wire System for Incandescent Lamps...214, 215

Torque of Motor, Definition of 174
Torque, Variable and Constant Speed, Conditions of, in Motor 181, 182
Torque, Variable, and Variable Speed, Conditions of in Motor 182, 183
Tractive Magnets, Definition of............ 117
Transformer, Alternating-Current.........273 to 280
Transformer Circuits, Safety Fuse in.................. 278
Transformer, Eddy Current Losses in 275
Transformer, Efficiency of 278, 279
Transformer, Hysteresis Loss in.................. 276
Transformer, Laminations of Core of............. 275
Transformer, Limitation of Rise of Temperature in.. 277
Transformer, Power Factor of 280
Transformer, Step-Down, Definition of............ 274
Transformer, Step-Up, Definition of............... 274
Translating Devices, Classification of 59
Translating Devices, Definition of................ 57
Tregohm, Definition of.... 31
Triangular Triphase winding................... 270
Triphase E. M. F's Diagram 271
Triphasers................ 267

Turns, Ampere, Definition of 95
Twin-Wire Circuit..........251

Unit of Reluctance 103
Unit Rate of Electrical Flow.... ....44, 45
Unplugging, Definition of. 28
Useful or Available Work.. 8

Voltaic Arc................ 217
Voltaic Arc Light, Steadiness of, Circumstances Affecting 221
Voltaic Battery 12
Voltaic Battery, Necessity for Insulating........... 85
Voltaic Cell.......11, 65 to 88
Voltaic Cell, Closed Circuit Type of..............81, 82
Voltaic Cell, Cost of Electric Energy, produced by 82, 83
Voltaic Cell, Creeping of Electrolyte in 84
Voltaic Cell, Dry.......... 79
Voltaic Cell, Grenet....73, 74
Voltaic Cell, Open-Circuit Type of 81
Voltaic Cell, Polarization of 70
Voltaic Cell, Porous Cell or Partition of........... 75
Voltaic Cell, Silver Chloride 78
Voltaic Couple, Definition of 66
Voltaic Elements, Definition of.................. 66
Voltaic Pair, Definition of 66

Water, Effect of Impurities on Resistance of 25

Water, Pure, Electric Resistance of........ .. . 25
Wave, Fundamental, Definition of 263
Waves, Sinusoidal, Definition of..............236, 237
Wheatstone's Balance...27, 28
Wheatstone's Bridge....27, 28
Winding, Armature, M. M. F., Produced by............ 120
Winding, Triangular Triphase 270
Windings, Star Triphase . 270
Wire, Fuse 197
Wire Gauge, American, Table of................ 35
Wires, Leading-in......... 201
Work, Common Stock of.. 6
Work, Definition of........ 4
Work Done by Electric Current 6
Work, Law of............ 5
Work, Useful or Available. 8

Zig-Zag Magnet,... 119
Zig-Zag Type of Alternating Electromotive Force or Current. 236
Zinc, Amalgamation of, in Voltaic Cell............. 69
Zinc-Copper Couple....... 66

ERRATA.

Page 18, ¶ 27. For $\frac{645}{10000}$ read $\frac{1}{645}$.
" 157, " 195. " tension read attention.
" 172, " 109, 8th line. For five read four.
" 175, " 111, 19th line. For $13\frac{4}{10}$ read 134.
" 175, " 111, 19th line. For 10 KW. read 100 KW.